AD-787 042

# CONSTRAINTS ON CIVIL DEFENSE OPERATIONS IN PHYSICALLY DAMAGED AREAS

Carl F. Miller

Dikewood Corporation

Prepared for:

Defense Civil Preparedness Agency

September 1974

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1 REPORT NUMBER | 2 GOVT ACCESSION NO | 3 RECIPIENT'S CATALOG NUMBER AD 787 042 |
| 4 TITLE (and Subtitle) Constraints on Civil Defense Operations in Physically Damaged Areas | | 5 TYPE OF REPORT & PERIOD COVERED Final Report |
| | | 6 PERFORMING ORG REPORT NUMBER |
| 7 AUTHOR(s) Carl F. Miller | | 8 CONTRACT OR GRANT NUMBER(s) DAHC20-72-C-0313 |
| 9 PERFORMING ORGANIZATION NAME AND ADDRESS Defense Civil Preparedness Agency Washington, D. C. 20301 | | 10 PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS Work Unit 3538A |
| 11 CONTROLLING OFFICE NAME AND ADDRESS Defense Civil Preparedness Agency Washington, D.C. 20301 | | 12 REPORT DATE Feb. 1973-Printed Sept. 1974 |
| | | 13 NUMBER OF PAGES 78 |
| 14 MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15 SECURITY CLASS (of this report) Unclassified |
| | | 15a DECLASSIFICATION DOWNGRADING SCHEDULE |

16 DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17 DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18 SUPPLEMENTARY NOTES

19 KEY WORDS (Continue on reverse side if necessary and identify by block number)

| | | | |
|---|---|---|---|
| Civil Defense | Nuclear War | Damage | Recovery Planning |
| Postattack | Survival | Radiological | |
| Nuclear Emergency | Countermeasures | Hazards | |
| Recovery | Fallout | Operating Situations | |

20 ABSTRACT (Continue on reverse side if necessary and identify by block number)

Constraints on civil defense operations that may be imposed by attack effects in urban areas that are exposed to blast and thermal effects of nuclear explosions have been analyzed, discussed and summarized. The peripheral constraint in both the emergency period and the post-attack period on the conduct of operations appears to be debris in the street. The presence of debris in many

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

urban configurations would constrain and limit such actions as fire-fighting and rescue in the emergency phase and such actions as remedial movement, damage repair, and facility operations in the postattack period. Thus, debris removal would be one of the most important initial countermeasures for damaged urban areas.

The results of an empirically-based debris production model have been summarized and extended. In addition, certain dynamic and gross features of fire propagation and damage have been summarized. Because of the importance of early detection and suppression of ignitions in the control of fires, knowledge of the early-time dynamics of fire-ignition and spread needs widest generalization, clarification, and distribution.

Several transattack and postattack hazard situations are described according to a commonly-used 3x3 matrix describing a 3-step or 3-level hazard situation in both fallout radiation and in physical damage. For each case discussed, principal countermeasure options are listed and information needs for each are summarized. The analysis indicated that, for nuclear explosion effects on a warned population in modern urban areas, the blast effect will be more casualty-producing than the thermal effect.

Final Report

DCPA Work Unit 3538A
February 1973
Printed September 1974

# CONSTRAINTS ON CIVIL DEFENSE OPERATIONS IN PHYSICALLY DAMAGED AREAS

DCPA Contract No. DAHC20-72-C-0313

Prepared for:

DEFENSE CIVIL PREPAREDNESS AGENCY
Washington, D. C. 20301

By: Carl F. Miller, Dikewood Corporation*

This report has been reviewed in the Defense Civil Preparedness Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Defense Civil Preparedness Agency.

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

* Now with Center for Planning and Research

1b

# SUMMARY

Constraints on civil defense operations that may be imposed by attack effects in urban areas that are exposed to blast and thermal effects of nuclear explosions have been analyzed, discussed and summarized. The peripheral constraint in both the emergency period and the post-attack period on the conduct of operations appears to be debris in the street. The presence of debris in many urban configurations would constrain and limit such actions as firefighting and rescue in the emergency phase and such actions as remedial movement, damage repair, and facility operations in the postattack period. Thus, debris removal would be one of the most important initial countermeasures for damaged urban areas.

The results of an empirically-based debris production model have been summarized and extended. In addition, certain dynamic and gross features of fire propagation and damage have been summarized. Because of the importance of early detection and suppression of ignitions in the control of fires, knowledge of the early-time dynamics of fire-egnition and spread needs widest generalization, clarification, and distribution.

Several transattack and postattack hazard situations are described according to a commonly-used 3x3 matrix describing a 3-step or 3-level hazard situation in both fallout radiation and in physical damage. For each case discussed, principal countermeasure options are listed and information needs for each are summarized. The analysis indicated that, for nuclear explosion effects on a warned population in modern urban areas, the blast effect will be more casualty-producing than the thermal effect.

## CONTENTS

## ILLUSTRATIONS

## TABLES

TABLES (Continued)

## INTRODUCTION

To specify constraints or limiting conditions on operations in physically damaged areas, some description of the damaged area and the obstacles that may be encountered in the conduct of operations is needed. To bound the scope of discussion, organizational problems are not discussed. In general, civil defense operations in a physically damaged area which involve the movement of tasks groups (and their vehicles and equipment) at any time after attack over any given time interval may be constrained by (1) the amount of debris in the streets and roadways, (2) the intensity of fires, and/or (3) the magnitude of the radiation hazard from radioactive fallout. Occasionally, these effects (now viewed as operational constraints) are erroneously depicted as having intensities which decrease rapidly with distance from ground zero of a detonation; this generalized depiction is erroneous because a target area of uniform characteristics and responses is implied whereas target area characteristics are not uniform over the range of the effects and the target responses may be changed by the effects incurred. These aspects of the involved phenomena are discussed below; in general, the specification of realistic operational constraints involves answers to the question of whether (and what) civil defense operations would be feasible to conduct at any selected location within a damaged area.

The definition of precisely what a damaged area consists of is probably not very important by itself. Visual consequences, overpressure indications (e.g., 1 psi), or thermal measurements (e.g., 1 cal/sq cm) could be used to arbitrarily define boundary conditions for any needed purpose. However, when mobile operations are considered for any location of interest, the effects of damage on such operations would determine the condition which specifies the peripheral limit of the damaged area. To clarify, some properties and characteristics of damaged urban areas relative to intensity of effects are discussed below.

The following general description of a physically damaged urban area resulting from a nuclear detonation includes specification of both blast effects and fire effects; for if the detonation is near ground surface the fallout radiation hazard would be superimposed on parts of the damaged area. A summary of effects that might be observed in the damaged area resulting from a 5-MT (50% fission) yield surface detonation would be as follows:[1, 2, 3]

| | | |
|---|---|---|
| 1. | Upwind distance to the $I_s^{\circ}$ contour of 100 R/hr at 1 hr . . . . . . . . . . . . . . . . . . . | 3.9 miles |
| 2. | Crosswind distance to the $I_s^{\circ}$ contour of 100 R/hr at 1 hr . . . . . . . . . . . . . . . . . . . | 3.9 miles |
| 3. | Upwind distance to the $I_s^{\circ}$ contour of 1.0 R/hr at 1 hr . . . . . . . . . . . . . . . . . . . | 10.0 miles |
| 4. | Crosswind distance to the $I_s^{\circ}$ contour of 1.0 R/hr at 1 hr . . . . . . . . . . . . . . . . . . . | 9.2 miles |
| 5. | Earliest fallout arrival time. . . . . . . . . . | 22 minutes |
| 6. | Distance to about 100 cal/sq cm thermal radiation[a] | 4.0 miles |
| 7. | Limiting distance for thermal ignitions in houses[a] (colored curtains, upholstery, etc.). . . . . . | 9.0 miles |
| 8. | Distance to an overpressure of 6 psi . . . . . | 4.2 miles |
| 9. | Distance to an overpressure of 2 psi . . . . . | 8.1 miles |
| 10. | Distance to an overpressure of 1 psi . . . . . | 12.3 miles |

At an overpressure of about 6 psi (i.e., at 4.0 to 4.2 miles from ground zero), the following types of damage would be expected: frame houses flattened; brick houses and apartment building blown over and the bricks (or pieces of them) strewn about; exterior walls of multistory wall-bearing monumental buildings and reinforced concrete buildings badly cracked, interior partitions torn apart or blown out, structural frame distorted, extensive spalling of concrete; heavy steel-frame industrial buildings (25 to 50 ton crane) sustaining some distortion to the frame; larger, heavier buildings showing smaller amounts of damage; cars and trucks turned over, displaced, badly dented, frames sprung; trees uprooted; telephone poles broken; railroad car doors demolished, frames distorted.

[a]For a visibility of about 10 miles

In residential areas the average depths of debris would range up to 6 inches, depending on building density; in typical builtup industrail areas, the average depth would be as much as 4 feet; and in heavy builtup commercial areas, the average depth of rubble could exceed 10 feet.[4]

At distances less than 4 miles from ground zero, blast damage to heavier buildings would be more severe and where such buildings would be present in high density (e.g., heavy commercial), the debris depths would be somewhat larger than those given above. In similarly affected areas containing structures that are severely damaged at 6 psi, no significant increase in debris would be expected on the basis of higher overpressures. At these distances from ground zero, it is likely that most streets except perhaps those in the very sparsely builtup residential areas and the roads and highways which pass through broad open areas would be impassable to vehicular traffic until cleared of debris. Thus the structural damage and amount of debris produced where the incident overpressure is 6 psi would represent a condition or situation which would prohibit immediate access for the conduct of a number of civil defense operations and which would deny the area to all tasks groups with rubber-tired vehicles.

Light damage to many structures (window breakage, especially) is indicated above as occurring at distances of 8 to 12 miles from ground zero where the blast overpressure would be between 1 and 2 psi. In such areas near the periphery of the damaged area, the broken glass and other items might be sufficient to retard or slow the movement of rubber-tired vehicles. In the region subjected to overpressures of less than 2 psi, restrictions on movement due to debris in the streets would generally be minimal except perhaps for some residential and industrial areas. Depending on building type and density, typical maximum depths of debris at the 2 psi contour could be as follows: (1) residential - 2 feet; (2) commercial - 6 inches; and (3) light industrial - 12 inches. These levels indicate definite difficulty for movement of vehicles in streets adjacent to buildings subjected

to an overpressure of 2 psi. (Further restriction in movement due to fall-out in these peripheral areas would occur only in the sectors situated more or less in the downwind direction from ground zero.)

The limiting distance for fire ignitions in residential houses and other such buildings with exposed windows and flammable materials in outside rooms, not considering the possibility of fire spread, is about 9 miles for the 5-MT surface detonation where the visibility is about 10 miles. Thus fires could readily be started in buildings subject to light damage shortly after fire ignition. Many of these ignitions would be suppressed by the blast wave with an intensity of 2 to 5 (or higher) psi, or in the ring located at a distance range of about 5 to 8 miles from ground zero. In this view, the more distance ring of remaining ignitions at a distance of 8 to 9 miles could be the source of uncontrolled mass fires, depending on the density of the buildings and their fuel content. It is well known from World War II experience that the lightly damaged buildings would be more likely to produce mass fire or firestorm-like conditions than would the heavily damaged or flattened buildings located in the areas subjected to incident overpessures greater than 5 psi.

The high concern in the recent past about the severity of possible fire effects following a nuclear detonation in an urban area, appears to have resulted from a straightforward extrapolation of World War II experience where, in the air attacks on cities in Europe and Asia, fire effects caused more damage to urban structures and more human casualties than did blast effects. The relative effect of fire was apparently magnified in the large scale attacks on cities (e.g., Hamburg, Tokyo, Hiroshima, Dresden, and Nagasaki). Since then arguments have been formulated to show that direct extrapolation of the data regarding the firestorm or conflagration threat, from World War II experience to conditions that may apply in a possible nuclear war in the future (or even at this time), does not accurately reflect knowledge of large scale nuclear detonation effects nor the response of target components with different fire-support characteristics.

For example, the structures in the areas where firestorms are believed to have occurred in World War II generally consisted of 2 or 3 story buildings constructed mostly of wood. Modern cities contain many multistory buildings with a much lower fuel loading per floor. The streets of the old cities in which firestorms occurred were very narrow; in modern cities the streets are often more than three times wider. In each firestorm incident, the blast damage over the affected area was relatively light, serving mainly to break windows and to blast holes in roofs. Such effects facilitated the free flow of air to fires ignited by fire bombs; in all such fires, the structures burned without being previously destroyed or flattened by large scale blast effects. Such a condition would not prevail in a similarly constructed urban area subjected to the combined blast and thermal effects from a nearby nuclear explosion in the megaton yield range and it would be less likely to prevail in a modernized urban area. With exposure to an overpressure of 6 psi or greater, the complete collapse of the more combustible structures would result in burial of much of the fuel. Instead of opening up the structures for free flow of air, the large scale nuclear effects would flatten them so that the flow of air to the fuel would be restricted. A number of German fire experts who observed the firestorms in World War II have concluded that similar fires, especially the firestorms, would not occur in the rebuilt sections of the bombed-out cities if they were now similarly attacked with nuclear weapons.

The above descriptions for the damaged area indicate without question that, where the overpressure would exceed 5 or 6 psi and where the incident thermal radiation would exceed 100 cal/sq cm in an urban area many fires would be ignited and would not be extinguished by the blast wave. In addition, many fires would be ignited by secondary effects. In areas where these effects occur, it is expected that the fires would burn uncontrolled (1) because blast-caused damage would result in loss of available water for fighting fires, (2) because streets would be impassable due to debris and fire fighting equipment would not be able to reach the fires area, (3) because

casualties among firefighting crews and their equipment could be relatively high, and (4) because the fire area would be too large for currently available forces to cope with. These consequences would constrain if not deny the possibility of conducting firefighting operations in such an affected area.

In the peripheral regions of a damaged area where thermal ignitions from a large yield nuclear explosion are possible (especially in clear weather conditions), possibilities for a large scale fire would be highest, as indicated above. Further, in this region, the possibilities for firefighting could exist without severe constraint due to debris in the streets. If the ignitions in structures in these areas are not extinguished within a few minutes after ignition, (the blast effect for extinguishing fires is apparently non-existent at overpressures less than 2 psi) room flashovers would quickly follow and the fires could then rapidly spread, external conditions permitting (weather, etc.). The possibility of movement of people (evacuation) and of firefighting crews within the burning area (or to its edge) will generally not depend on fire density (the number of fires per unit area) or on the size of the burning area, but on the intensity of the heat in the streets from the fires. For mass fires in urban structures, the peak intensity would probably not develop until about one hour or more after ignition. The peak burning rate might be reached within 30 minutes after ignition for single unit fires in residential areas. Actual intensities for which movement in the streets would become virtually impossible should depend on the average fuel loading over a fairly large area. The conditions for this constraint from past experience is described below.

Where intensities of heat or thermal flux sufficient to deny access to the area (to the point of causing fatalities in the streets) occurred in previous large scale urban fires, the average fuel loading ranged from about the equivalent of 8 lbs of wood/sq ft (Hiroshima) to 32 lbs of wood/sq ft (Hamburg). Thus, in urban areas where the equivalent fuel loading is less than about 10 to 20 lbs of wood per sq ft and where the streets are wider than those of pre-World War II Hamburg or Hiroshima, movement in the street should

be possible during the course of the fire, neglecting any operation hindrance due to debris as applicable to the peripheral area conditions.*

From the physical descriptions given regarding the likely fire conditions in the peripheral regions of the damaged area for fire-susceptible construction, it may be concluded that fires in these regions would be more like those observed in Europe in World War II than those in areas subjected to an incident overpressures of the order of 6 psi, if correspondingly high fuel loadings exist. At the lower overpressure, essentially all structures would remain upright with windows broken and some doors blown down, a condition providing ready access of air to interior fuels. At the higher overpressure, the fuels would be flattened, compacted, buried, and mixed with all kinds of non-flammable debris.

---

*The numerical figures given in the text are only for discussion purposes; additional study is needed to indicate if these or other values would be more appropriate for use in planning transattack firefighting operations. In the Hammerbrook district of Hamburg where a firestorm is believed to have occurred, the gross average fuel density is estimated to have been, prior to the fire, equal to 32 lbs of wood/sq ft with an average building density, in terms of the area covered by structures divided by the total area (including streets and open areas), of 0.439. The structures in the area therefore characteristically contained about 73 lbs of wood for each sq ft of built-on area with an average of almost 2 stories per structure. The casualty rate was considerably lower in the Eimsbuttel district than in the Hammerbrook district; however, no valid deductions can be made regarding the relative fire hazard to the exposed population at risk in the two cases since many people left Hamburg after the Hammerbrook district fire and the population density of the Eimsbuttel district is not reliably known and certainly was not normal. In the Hammerbrook area, essentially 100 percent of the structures were destroyed or burned out; in the Eimsbuttel area, about 84 percent of the structures were destroyed or burned out. The weather conditions were also different and the unusually favorable dry and calm atmospheric conditions during the Hammerbrook fire is often mentioned as being at least as important as the target characteristics in leading to the firestorm. But both were uncontrolled mass fires with a relatively high density of exposed fuels where many opportunities for escape with preparation existed (under wetted blankets, etc.). More feasible movement should certainly be feasible for areas with lower fuel densities providing debris production does not negate this feasibility.[3]

The general conclusion is the fire fighting operations would be feasible in urban areas where the effects of damage is less than that expected from an incident overpressure of about 2 psi. In these peripheral areas, a self-help organization could be effective in stopping the interior spread of fires. If initial suppression efforts fail, effective fire fighting and rescue operations could be limited later on due to high fire intensities.

Constraints on operations due to fallout hazards are discussed in a companion report. However, it may be mentioned here that in terms of hazard to life, the immediate effects of blast and fire would tend to predominate over possible over-exposure to radiation and that time for early suppression of ignitions should be available before fallout from the same weapon would arrive in full force. To be successful, the fire suppression must occur before first flashover in any room of a building. A few points on human survival rates in the damaged area are summarized below using the Japanese experience in World War II as a basis.

Despite the rather severe physical damage depicted above for urban target areas subjected to an overpressure of about 6 psi and an incident thermal radiation of 100 cal/sq cm, the survival rates of people could be quite high if they are property protected. The experience of the Japanese people of Hiroshima and Nagasaki in World War II would suggest that the survival rates could be surprisingly high; the survival rates (including the injured) immediately after those detonations, with adjustment to the 5-MT detonation conditions, are approximately as follows:[2]

| | | |
|---|---|---|
| 1. | Survival Rate in direct outside exposure (100 cal/sq cm, 6 psi) | 0% |
| 2. | Survival Rate in any building* or at an outside shielded location ( 100 cal/sq cm) | 90% |
| 3. | Survival Rate in wood frame buildings* (6 psi) | 85% |
| 4. | Survival Rate in concrete buildings* (6 psi) | 95% |
| 5. | Survival Rate in underground shelter (6 psi) | 100% |

*Many of these buildings subsequently were gutted or completely destroyed by fire (most wood frame structures were flattened by the blast).

The overall survival rates, where the overpressure was about 6 psi, were about 60 percent at both Hiroshima and Hagasaki. At the range of this overpressure, the incident thermal radiation for the lower yield air bursts was less intense than that indicated for the 5-MT yield surface detonation. For the same yield and atmospheric conditions, the relative distance from ground zero to the incident radiation of 100 cal/sq cm is larger than the range to the 6 psi contour for air bursts than for surface bursts. The range for both effects, of course, increases with burst height up to the point at which the maximum range of the overpressure occurs; for a 5-MT detonation this height is about 20,000 ft for the 6 psi contour. At higher burst heights, the thermal effects would predominate.

The overall survival rates of 60 percent for the Hiroshima and Nagasaki detonations indicate that major contributing effects causing the immediate fatalities (i.e., those who died within the first few days after detonation) were: (1) direct exposure to the incident thermal radiation, (2) fire effects on trapped survivors, and (3) indirectly, blast effects for persons in wood frame buildings, which immobilized the occupants through injury or entrapment.

Since blast casualties among persons in buildings at the time of attack would be caused mainly by secondary effects (translation, missiles, and structural collapse), the structural characteristics of materials of modern structures should be of some importance with respect to the incidence of blast injury. It is expected that those materials which tend to improve the structural resistance to fire also tend to enhance the casualty-producing potential following structural blast-loading and collapse (e.g., steel, sheet metal, concrete, brick, and glass; large multistory; many moveable objects, utensils, and paraphernalia in rooms, offices and shops within a building).

In summary, it may be concluded, on the basis of the constraints on operations, that the perimeter of the damaged area should coincide with the limiting range to physically damaged structures where movement

immediately thereafter would, for the most part, be hindered by debris in the adjacent streets. Uncontrolled fires could occur out to the periphery of the damaged area in built-up areas of sufficiently high fuel loading Debris in the streets would surely hinder firefighting operations in urban areas where the incident overpressure exceeded 2 psi. However, in peripheral areas where the debris would not be a hindrance to operations, the fire intensity could possibly prohibit firefighting operations; but such a condition should occur only in areas of highest fuel loading sufficient for a possible mass fire to develop. Hence it appears that fire hazards have a probability or potential for occurence anywhere and everywhere within the defined damage perimeter which depends mainly on the surface density and distribution of structures and the relevant fire susceptibility characteristics, and on the capability of the firefighting forces to conduct operations (i. e., to move about in the area and have ready access to sources of water).

At the distance from ground zero where an overpressure of 4 to 6 psi would impact on the target area, the resulting physical damage and amounts of debris in the streets of most typical urban built-up areas would certainly be sufficiently to halt all vehicular movement in the area. The fire intensity within such areas would not be expected to be as severe as it could be in the peripheral areas farther from ground zero because of burial of fuels within the debris. Due to the presence of larger amounts of debris, civil defense operations within the area would probably be limited to those that could be conducted without vehicles and without power-driven equipment. The main purpose of such operations would be to rescue and evacuate survivors. (Operations could be further restricted within about 30 minutes by fallout arrival; for the illustrated 5-MT detonation the upwind and crosswind distances to the 100 R/hr at 1 hr fallout contour are located almost 4 miles from ground zero.)

Thus in considering simultaneously the weapon effects output and target responses thereto relative to the conduct of the operations in the damaged area, it would appear that the operations would be constrained in the majority of cases by the presence of debris (neglecting the radiological hazard).

Although the fire hazard would persist for some time after the blast damage occurred, the time aspect is relevant only if operations are constrained. The aspects of time regarding the threat to life from blast and fire effects, separate or combined, are important with respect to the use of various countermeasures to save lives. The blast effect is over in a relatively short period whereas fires in structures build up more slowly to peak intensities after which the fires move on or burn out. Essentially no time is available for escape or other action against the blast effect during the life-time of the blast phenomena; some time is available for escape or other action against the fire effect. However, rescue actions for the removal of survivors (including the injured) trapped in blast-damaged structures would generally be applicable, where feasible, to operations up to 48 hours or more after attack; firefighting operations also would be applicable, where feasible, for about the same period of time.

Thus, with respect to applicable civil defense operations and their lifesaving potential, the blast effects could persist about as long as the fire threat, at least insofar as the consequences to the surviving population still at risk are concerned. The controllability of fires, except for areas where fire susceptibility characteristics are such that mass fires could not develop, would generally not be known for some time after detonation (except arbitrarily on the basis of assignment by fire-fighting forces). In addition, the relative distributions of threat forms and population could also depend on how contingency plans for shelters and other

preparedness plans are put into effect during a crisis period (e.g., by strengthening the current sheltering systems in central cities or by evacuation of the people to prepared rural locations).

## DEBRIS FORMATION ESTIMATING RELATIONSHIPS

The estimation of debris levels from blast-damaged urban structures generally involves determination of (1) the potential amount of debris that could result from destruction of a building or other object, (2) the amount of this debris which may land in adjacent streets and lots (offsite to the land on which the structure is built), and (3) the dependence of the latter on blast and shock effects (with or without fire).

The first term of significance in the debris formation relationship is the contained volume of the buildings in a block per unit length of street along any street side of a block; the numerical value of the contained volume of the buildings is calculated from[4, 5]

$$V/\ell = (EBW)\,\overline{H} \qquad \text{cu ft/ft} \tag{1}$$

in which $\overline{H}$ is the average height of the buildings in ft, EBW is the equivalent building width of a single structure around the whole perimeter of the block whose volume is approximately equal to the sum of the volumes of the buildings on the block, and $\ell$ represents either L or W where L is the length and W is the width of the block. The general equation for EBW is

$$EBW = \frac{(L + W)}{4} - \frac{1}{4}\sqrt{(L + W)^2 - 4CWL} \tag{2}$$

in which letter C represents the fraction of the block area covered by structures. Representative values of the EBW for blocks of different sizes and fraction of builtupness are summarized in Table 1.

A summary description of 20 building types for debris estimation purposes is given in Table 2; each type may be categorized somewhat differently in terms of its conversion to debris by blast effects, with respect to both the amount and character of the debris. The latter should depend on the structural materials in the building and on the characteristics of the

Table 1

Summary of Equivalent Building Width (EBW) Values

| | Block Dimensions (LxW) | | | | | |
|---|---|---|---|---|---|---|
| C | 300 x 100 | 200 x 200 | 300 x 200 | 300 x 300 | 300 x 400 | 400 x 400 |
| 0.10 | 3.8 | 5.1 | 6.2 | 7.6 | 8.8 | 11 |
| 0.20 | 8.0 | 11 | 13 | 16 | 18 | 21 |
| 0.30 | 12 | 16 | 20 | 25 | 28 | 33 |
| 0.40 | 16 | 23 | 27 | 34 | 39 | 45 |
| 0.50 | 21 | 30 | 35 | 44 | 50 | 59 |
| 0.60 | 26 | 37 | 44 | 55 | 63 | 73 |
| 0.70 | 30 | 46 | 54 | 68 | 77 | 90 |
| 0.80 | 37 | 56 | 65 | 84 | 94 | 110 |
| 0.90 | 43 | 68 | 79 | 103 | 115 | 136 |
| 1.00 | 50 | 100 | 100 | 150 | 150 | 200 |

Table 2

Summary of Types of Buildings Considered For Debris Estimation

| Type No. | Building Description |
|---|---|
| 1 | Wood Frame |
| 2 | Unreinforced Masonry Load - Bearing Wall |
| 3 | Light Steel Frame Industrial - Corrugates Asbestos Sheathing |
| 4 | Light Steel Frame Industrial - Corrugated Metal Sheathing |
| 5 | Medium Steel Frame Industrial - Corrugated Asbestos Sheathing |
| 6 | Medium Steel Frame Industrial - Corrugated Metal Sheathing |
| 7 | Heavy Steel Frame Industrial - Corrugated Asbestos Sheathing |
| 8 | Heavy Steel Frame Industrial - Corrugated Metal Sheathing |
| 9 | Multistory Heavy Reinforced Concrete Shearwall - Light Interior Panels |
| 10 | Multistory Heavy Reinforced Concrete Shearwall - Masonry Interior Panels |
| 11 | Multistory Reinforced Concrete Shearwall - Light Interior Panels |
| 12 | Multistory Reinforced Concrete Shearwall - Masonry Interior Panels |
| 13 | Multistory Steel or Reinforced Concrete Frame - Light Exterior Panels - Non Earthquake |
| 14 | Multistory Steel or Reinforced Concrete Frame - Masonry Exterior Panels - Non Earthquake |
| 15 | Multistory Steel or Reinforced Concrete Frame - Light Exterior Panels - Earthquake |
| 16 | Light Reinforced Concrete Frame - Masonry Exterior Panels - Earthquake |
| 17 | Light Reinforced Concrete Shearwall - Concrete Roof - Light Interior Panels |
| 18 | Light Reinforced Concrete Shearwall - Concrete Roof - Masonry Interior Panels |
| 19 | Light Reinforced Concrete Shearwall - Mill Type Roof - Light Interior Panels |
| 20 | Light Reinforced Concrete Shearwall - Mill Type Roof - Masonry Interior Panels |

building contents. The characteristic amounts and types of content material depend on building usage.

The volume of potential debris material from a block of buildings is estimated from

$$V_D/\ell = (DF)\ V/\ell \qquad (3)$$

where (DF) represents the debris factor, a term which converts the contained volume of the buildings to gross volume of debris. Debris factor values for the 20 building types with 3 different types of usage are summarized in Table 3 for the cases where only blast effects are involved as well as where blast plus fire effects are involved.

For more generalized planning applications, the debris factors of Table 3 are summarized as follows:

| | Structural Type | Blast Effects | Blast & Fire Effects |
|---|---|---|---|
| 1. | Wood Frame Houses | 0.22 | 0.026 |
| 2. | Multistory Apartments | 0.31 | 0.16 |
| 3. | Light Commercial | 0.16 | 0.041 |
| 4. | Commercial | 0.40 | 0.20 |
| 5. | Light Industrial | 0.19 | 0.050 |
| 6. | Industrial | 0.35 | 0.20 |

The blast effect creates debris and then transports it from its place of origin to a resting place either on or off the original building site. The capability and potential for creating debris as well as for transporting the debris to offsite locations (mainly to the adjacent streets) is represented by the so-called offsite debris factor, designated $F_o$, whose value depends on both the building type and the overpressure. Nominal values of $F_o$ are summarized in Table 4 at selected blast overpressures for each of the 20 building types. A schematic representation of structural damage in the 3 usual categories (light, moderate, and severe) is shown in Figure 1. It can be seen, especially for the sturdier buildings, that the value of $F_o$

Figure 1. Degree of Damage-Debris Generation Chart

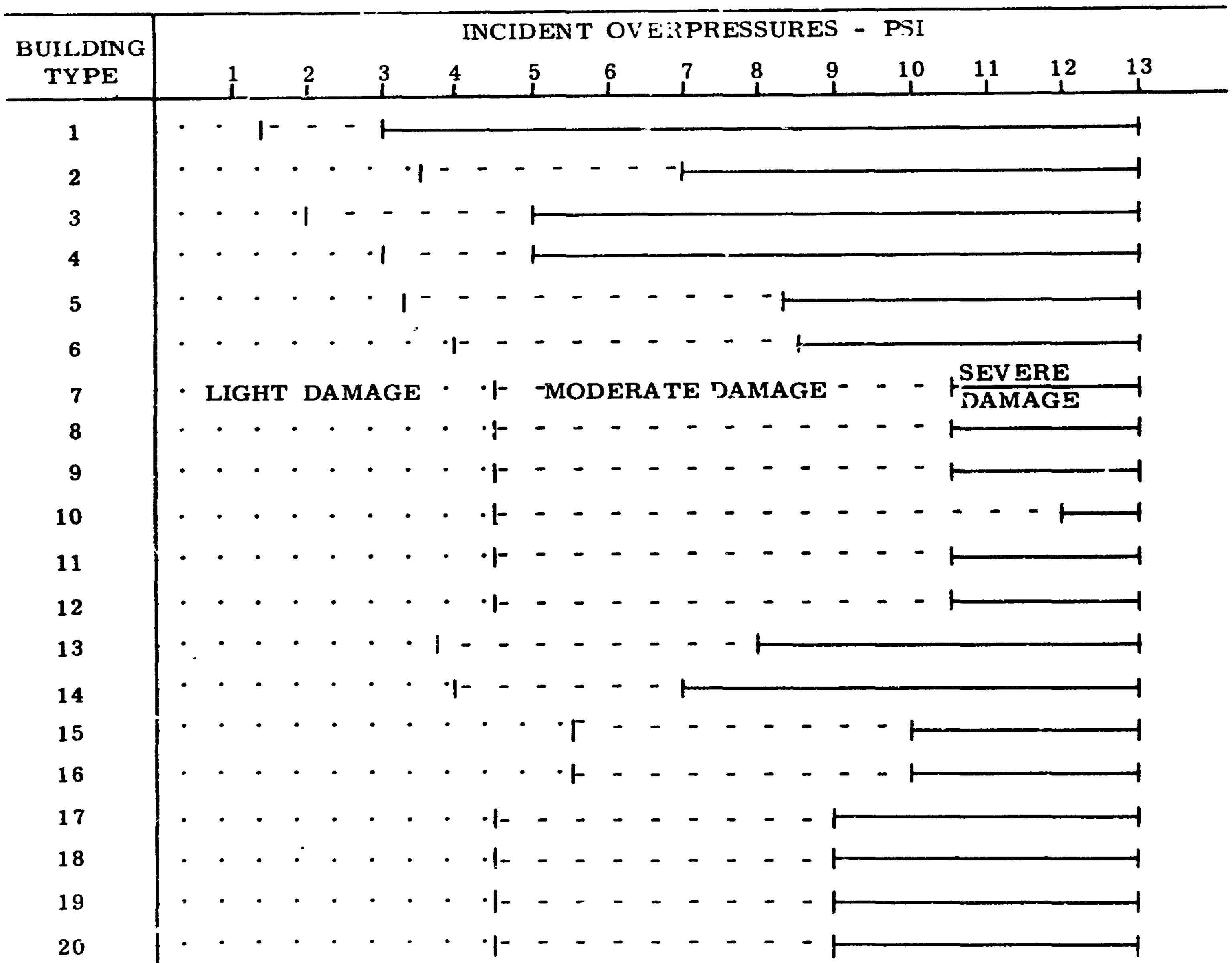


Table 3

Summary of Debris Factor Values for Various Building Types

| Building Type | Blast Effects | | | Blast & Fire Effects | | |
|---|---|---|---|---|---|---|
| | Res | Com | Ind | Res | Com | Ind |
| 1 | 0.218 | 0.354 | | 0.026 | 0.076 | |
| 2 | 0.378 | 0.494 | 0.390 | 0.186 | 0.230 | 0.216 |
| 3 | - | 0.164 | 0.188 | - | 0.040 | 0.052 |
| 4 | - | 0.158 | 0.182 | - | 0.034 | 0.046 |
| 5 | - | 0.162 | 0.188 | - | 0.040 | 0.052 |
| 6 | - | 0.160 | 0.184 | - | 0.036 | 0.048 |
| 7 | - | 0.166 | 0.190 | - | 0.042 | 0.054 |
| 8 | - | 0.160 | 0.184 | - | 0.036 | 0.048 |
| 9 | - | 0.380 | 0.456 | - | 0.216 | 0.242 |
| 10 | - | 0.460 | 0.536 | - | 0.296 | 0.322 |
| 11 | 0.276 | 0.406 | 0.290 | 0.132 | 0.180 | 0.162 |
| 12 | 0.376 | 0.506 | 0.390 | 0.230 | 0.278 | 0.260 |
| 13 | 0.256 | 0.392 | 0.138 | 0.116 | 0.164 | 0.146 |
| 14 | 0.330 | 0.466 | 0.350 | 0.190 | 0.238 | 0.220 |
| 15 | 0.270 | 0.406 | 0.290 | 0.130 | 0.178 | 0.160 |
| 16 | 0.350 | 0.486 | 0.370 | 0.208 | 0.256 | 0.238 |
| 17 | 0.280 | 0.340 | 0.320 | 0.134 | 0.168 | 0.172 |
| 18 | 0.290 | 0.350 | 0.330 | 0.148 | 0.182 | 0.186 |
| 19 | - | 0.274 | 0.254 | - | 0.102 | 0.106 |
| 20 | - | 0.300 | 0.280 | - | 0.132 | 0.136 |

Note: Res = Residential; Com = Commercial; Ind = Industrial

Table 4

Summary of Values of Off Site Debris Factor, $F_o$, For Various Building Types And Various Overpressures

| Bldg Type | Overpressure (psi) 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0.034 | 0.27 | 0.50 | 0.60 | 0.65 | 0.68 | 0.69 | | | | | | | |
| 2 | 0 | 0 | 0 | 0.007 | 0.050 | 0.18 | 0.54 | 0.60 | | | | | | | |
| 3 | 0.20 | 0.50 | 0.60 | | | | | | | | | | | | |
| 4 | 0.055 | 0.22 | 0.30 | | | | | | | | | | | | |
| 5 | 0.17 | 0.40 | 0.60 | | | | | | | | | | | | |
| 6 | 0.025 | 0.10 | 0.15 | | | | | | | | | | | | |
| 7 | 0.081 | 0.30 | 0.40 | | | | | | | | | | | | |
| 8 | 0.025 | 0.10 | 0.15 | | | | | | | | | | | | |
| 9 | 0.002 | 0.006 | 0.010 | 0.027 | 0.033 | 0.043 | 0.067 | 0.080 | 0.11 | 0.13 | 0.15 | 0.17 | 0.19 | 0.20 | 0.22 |
| 10 | 0 | 0 | 0.005 | 0.017 | 0.042 | 0.072 | 0.12 | 0.16 | 0.22 | 0.29 | 0.36 | 0.40 | 0.45 | 0.50 | 0.50 |
| 11 | 0 | 0.003 | 0.008 | 0.017 | 0.028 | 0.043 | 0.060 | 0.081 | 0.11 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 |
| 12 | 0 | 0 | 0.006 | 0.025 | 0.053 | 0.096 | 0.14 | 0.22 | 0.28 | 0.36 | 0.40 | 0.45 | 0.50 | 0.50 | |
| 13 | 0 | 0.006 | 0.018 | 0.041 | 0.072 | 0.10 | 0.16 | 0.20 | 0.22 | 0.25 | 0.30 | | | | |
| 14 | 0 | 0 | 0.019 | 0.073 | 0.11 | 0.16 | 0.44 | 0.55 | 0.60 | 0.60 | | | | | |
| 15 | 0 | 0.002 | 0.009 | 0.025 | 0.045 | 0.072 | 0.10 | 0.14 | 0.20 | 0.25 | 0.30 | 0.30 | | | |
| 16 | 0 | 0 | 0.010 | 0.040 | 0.095 | 0.17 | 0.30 | 0.40 | 0.55 | 0.60 | 0.60 | | | | |
| 17 | 0 | 0.001 | 0.006 | 0.012 | 0.012 | 0.050 | 0.23 | 0.51 | 0.55 | 0.60 | 0.60 | | | | |
| 18 | 0 | 0 | 0.018 | 0.072 | 0.15 | 0.23 | 0.42 | 0.65 | 0.80 | 0.80 | | | | | |
| 19 | 0 | 0.033 | 0.132 | 0.30 | 0.35 | 0.40 | 0.40 | | | | | | | | |
| 20 | 0 | 0.006 | 0.101 | 0.29 | 0.53 | 0.65 | 0.65 | | | | | | | | |

is very small in the light damage region, that the value of $F_o$ increases rapidly with overpressure in the range where moderate damage occurs, and that the value of $F_o$ tends to gradually approach a constant value at overpressures greater than that required to cause severe damage.

For the six above-listed general building types, the $F_o$ values of Table 4 for building type No. 1 would apply to wood frame houses. The following values for $F_o$ may be used for (1) light commercial and industrial structures and (2) apartments, commercial, and industrial buildings, respectively:

| | Overpressure (psi) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| $F_o(1)$ | 0.071 | 0.22 | 0.32 | 0.38 | 0.41 | 0.42 | | | |
| $F_o(2)$ | 0.0016 | 0.0040 | 0.011 | 0.030 | 0.066 | 0.12 | 0.20 | 0.30 | 0.36 |

With the above definitions, the volume of offsite debris, $V_{DO}/\ell$, is estimated from

$$V_{DO}/\ell = F_o \, V_D/\ell \tag{4}$$

The average depth of debris in the street (or at other offsite locations), $\bar{d}$, is calculated by dividing $V_D/\ell$ by an apparent street width, $S_e$. The inverse of $S_e$, designated $\overline{F}_d$, is called the average debris depth factor. The value of both parameters depends on the dimensions of the block and the width of the street, S. Approximate values of $S_e$ may be calculated from

$$\frac{1}{\overline{F}_d} = S_e = (0.800 + 2.17\,WL^{-4/3})\,S^{1.101} \text{ ft} \tag{5}$$

A set of $\overline{F}_d$ values are given in Table 5 for various block dimensions and street widths. The average depth is given by

Table 5

Summary of Values of the Average Debris Depth Factor, $\overline{F}_d$, For Various Block Dimensions and Street Widths

| S (ft) | Block Dimensions (L x W) 300 x 100 | 200 x 200 | 300 x 200 | 300 x 200 | 300 x 400 | 400 x 400 |
|---|---|---|---|---|---|---|
| 30 | 0.026 | 0.020 | 0.023 | 0.021 | 0.023 | 0.022 |
| 40 | 0.019 | 0.015 | 0.017 | 0.015 | 0.017 | 0.016 |
| 50 | 0.015 | 0.011 | 0.013 | 0.012 | 0.013 | 0.012 |
| 60 | 0.14 | 0.009 | 0.011 | 0.0098 | 0.011 | 0.010 |
| 70 | 0.010 | 0.008 | 0.0092 | 0.0083 | 0.009 | 0.0085 |
| 80 | 0.0088 | 0.007 | 0.0079 | 0.0071 | 0.008 | 0.0073 |
| 90 | 0.0078 | 0.006 | 0.0070 | 0.0063 | 0.007 | 0.0065 |
| 100 | 0.0069 | 0.005 | 0.0062 | 0.0056 | 0.006 | 0.0057 |
| 110 | 0.0062 | 0.004 | 0.0056 | 0.0050 | 0.006 | 0.0052 |
| 120 | 0.0057 | 0.004 | 0.0051 | 0.0046 | 0.005 | 0.0047 |

$$\bar{d} = \bar{F}_d \, V_{DO}/\ell \qquad \text{ft} \tag{6}$$

or, upon combining Equations 1, 3, 4, and 6

$$\bar{d} = \bar{F}_d \, F_o \, (DF) \, (EBW) \, \bar{H} \tag{7}$$

The variability in the depth of debris apparently depends on the range in height of its origin, the width of the streets or area within which it is eventually confined, and the incident overpressure. Trends in the ratio of the maximum debris depth, $d_m$, to the average debris depth are shown by the ratio values given in Table 6 for several values of $\bar{H}/S$ and incident overpressure. The debris piles are indicated to be much steeper as the values of $\bar{H}/S$ and the overpressure become smaller.

Knowledge of the general size of the largest pieces of debris is important in debris removal (in determining the likely need for special equipment, in forecasting special problems to be expected, etc.). Approximate information on the size of the pieces of debris and its general content, which depend on building type, degree of damage, and building contents or usage are summarized in Table 7. The maximum size or dimension refers to a predominant maximum dimension of the pieces of debris not considering huge pieces of structural elements (such as beams, columns, or wall sections). The content code does refer to the predominant type of structural materials present (such as steel beams, wood beams, large pieces of reinforced concrete, piping, etc.). The key to the structural content code number is as follows:

1 - no wood, no steel

2 - no wood, light steel, concrete

3 - medium to heavy wood, no steel

4 - medium steel, concrete

5 - heavy steel, concrete

Table 6

Ratio of Maximum to Average Depth of Debris

| | Incident Overpressure (psi) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $\overline{H}/S$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 0.2 | 12 | 10 | 6 | 6 | 5 | 4 | 3 | 2 | 1 |
| 0.4 | 12 | 10 | 6 | 5 | 4 | 3 | 2 | 2 | 1 |
| 0.6 | 10 | 8 | 6 | 5 | 4 | 3 | 2 | 1 | |
| 0.8 | 8 | 6 | 5 | 4 | 3 | 2 | 1 | | |
| 1.0 | 8 | 5 | 5 | 4 | 3 | 2 | 1 | | |
| 1.2 | 6 | 5 | 4 | 3 | 2 | 1 | | | |
| 1.4 | 6 | 4 | 3 | 3 | 2 | 1 | | | |
| 1.6 | 6 | 4 | 3 | 2 | 2 | 1 | | | |
| 1.8 | 5 | 4 | 3 | 2 | 2 | 1 | | | |
| 2.0 | 5 | 4 | 3 | 2 | 2 | 1 | | | |
| 2.5 | 5 | 3 | 3 | 2 | 1 | | | | |
| 3.0 | 5 | 3 | 2 | 2 | 1 | | | | |
| 3.5 | 4 | 3 | 2 | 2 | 1 | | | | |
| 4.0 | 4 | 3 | 2 | 1 | | | | | |
| 4.5 | 3 | 2 | 2 | 1 | | | | | |
| 5.0 | 3 | 2 | 1 | | | | | | |
| 6.0 | 3 | 2 | 1 | | | | | | |
| 8.0 | 3 | 2 | 1 | | | | | | |
| 10.0 | 2 | 2 | 1 | | | | | | |

Table 7

The Maximum Dimension of Debris Pieces Depending on Building Type, Degree of Damage and Building Contents

| Bldg | Light Damage | | | | | | Moderate Damage | | | | | | Severe Damage | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Res | | Com | | Ind | | Res | | Com | | Ind | | Res | | Com | | Ind | |
| Type | D | CC | D | CC | D | CC | D | CC | D | CC | D | CC | D | CC | D | CC | D | CC |
| 1 | 3 | 1 | 6 | 1 | - | - | 14 | 2 | 20 | 3 | - | - | 30 | 2 | 30 | 3 | - | - |
| 2 | 18 | 1 | 24 | 1 | 24 | 3 | 30 | 1 | 30 | 3 | 24 | 3 | 30 | 1 | 36 | 3 | 36 | 4 |
| 3 | - | - | 12 | 3 | 12 | 3 | 0 | 0 | 24 | 3 | 30 | 4 | - | - | 30 | 3 | 48 | 4 |
| 4 | - | - | 12 | 3 | 12 | 3 | - | - | 24 | 3 | 30 | 4 | - | - | 40 | 3 | 48 | 4 |
| 5 | - | - | 6 | 3 | 18 | 3 | - | - | 48 | 3 | 60 | 4 | - | - | 60 | 5 | 72 | 5 |
| 6 | - | - | 6 | 3 | 18 | 3 | - | - | 48 | 3 | 60 | 4 | - | - | 60 | 5 | 72 | 5 |
| 7 | - | - | 6 | 1 | 24 | 3 | - | - | 48 | 4 | 60 | 4 | - | - | 72 | 5 | 72 | 5 |
| 8 | - | - | 6 | 1 | 24 | 3 | - | - | 48 | 4 | 60 | 4 | - | - | 72 | 5 | 72 | 5 |
| 9 | - | - | 36 | 3 | 36 | 3 | - | - | 60 | 4 | 48 | 4 | - | - | 72 | 5 | 72 | 5 |
| 10 | - | - | 24 | 3 | 36 | 3 | - | - | 60 | 4 | 48 | 4 | - | - | 72 | 5 | 72 | 5 |
| 11 | 30 | 3 | 30 | 3 | 36 | 3 | 48 | 4 | 60 | 4 | 72 | 5 | 72 | 5 | 72 | 5 | 72 | 5 |
| 12 | 30 | 3 | 30 | 3 | 36 | 3 | 48 | 4 | 60 | 4 | 72 | 5 | 72 | 5 | 72 | 5 | 72 | 5 |
| 13 | 30 | 3 | 36 | 4 | 48 | 4 | 48 | 3 | 60 | 5 | 60 | 5 | 60 | 4 | 72 | 5 | 72 | 5 |
| 14 | 14 | 3 | 30 | 3 | 36 | 3 | 30 | 3 | 48 | 4 | 48 | 4 | 48 | 5 | 60 | 5 | 60 | 5 |
| 15 | 14 | 1 | 24 | 3 | 24 | 3 | 30 | 3 | 48 | 4 | 48 | 4 | 30 | 5 | 60 | 5 | 60 | 5 |
| 16 | 14 | 1 | 30 | 3 | 30 | 3 | 30 | 3 | 48 | 4 | 48 | 4 | 48 | 5 | 60 | 5 | 60 | 5 |
| 17 | 30 | 3 | 36 | 3 | 36 | 3 | 48 | 3 | 48 | 4 | 48 | 5 | 60 | 4 | 72 | 5 | 72 | 5 |
| 18 | 30 | 3 | 36 | 3 | 36 | 3 | 48 | 3 | 48 | 4 | 48 | 5 | 60 | 4 | 72 | 5 | 72 | 5 |
| 19 | - | - | 24 | 3 | 36 | 3 | - | - | 36 | 3 | 48 | 3 | - | - | 60 | 5 | 60 | 5 |
| 20 | - | - | 24 | 3 | 36 | 3 | - | - | 36 | 3 | 48 | 3 | - | - | 60 | 5 | 60 | 5 |

D = Maximum Dimension in inches; CC = Structural Content Code

The term concrete includes brick, plaster material, stucco, etc., although the bulk of these materials would be broken into smaller pieces than those characterized by the maximum dimension parameter, D. A number designation system for debris of different characteristics, based on the structural content code numbers and predominant maximum dimension of pieces and average depth has been suggested by Wickham and Williamson (Operation Planning Debris Removal, Jacob Associates, San Francisco, Calif., July 1971); it is reproduced in Table 8.[5]

The amount of debris from utility poles, trees, and automobiles in heavily builtup areas with multistory buildings is generally included in the debris estimates for the streets of those areas. For automobiles, Wickham and Williamson suggest shifting the debris number designation to a higher depth and size category for medium to heavy traffic streets where lighter structures exist with some changes in content code also.

In areas where structures are less dense and smaller with respect to debris volume, the possible debris and street blockage due to broken trees and poles could be severe in terms of the use of the streets by motor vehicles. The methods described above are not applicable to this type of debris formation problem. Instead, the following estimating format is suggested in which an estimated fraction of poles with diameters up to 10-in will be splintered or broken off and a fraction of trees with trunks and branches up to 8-inches in diameter will be broken off and, where located along the edge of a street or highway and subjected to an incident blast wave that is not perpendicular to the direction of the thoroughfare, would probably cause blockage of the street. The fraction, for a single tree, would represent the probability that the tree would be damaged sufficiently to cause blockage of the street. The following fractions are suggested, applicable to the blast wave from a low-MT yield surface detonation (the respective overpressures would be higher for a KT-yield detonation and lower for a 5 to 10 MT yield detonation because drag forces are involved in the destructive mechanics):[1]

Table 8

Suggested Number Designation for Debris of Different Characteristics

| Number Designation | Range of D (inches) | Range of $\bar{d}$ (feet) | Structural Content |
|---|---|---|---|
| 1-1 | 1-6 | 0.1-1 | None |
| 1-2 | 1-6 | 0.1-1 | Wood |
| 2-3 | 7-14 | 1-3 | Light Steel |
| 3-1 | 15-30 | 3-6 | None |
| 3-2 | 15-30 | 3-6 | Wood |
| 3-3 | 15-30 | 3-6 | Light Steel |
| 3-4 | 15-30 | 3-6 | Medium Steel |
| 3-5 | 15-30 | 3-6 | Heavy Steel |
| 4-3 | 31-48 | 6-10 | Light Steel |
| 4-4 | 31-48 | 6-10 | Medium Steel |
| 4-5 | 31-48 | 6-10 | Heavy Steel |
| 5-3 | 49-60 | 10-15 | Light Steel |
| 5-4 | 49-60 | 10-15 | Medium Steel |
| 5-5 | 49-60 | 10-15 | Heavy Steel |
| 6-4 | 61-72 | 15-20 | Medium Steel |
| 6-5 | 61-72 | 15-20 | Heavy Steel |

| | Overpressure (psi) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Fraction Down (poles with wires) | - | 0.01 | 0.35 | 0.60 | 0.80 | 0.90 | 0.95 |
| Fraction Down (trees) | 0.01 | 0.18 | 0.50 | 0.74 | 0.90 | 0.95 | 0.98 |

The fraction down curves reflect a rather rapid rate of increase in incidence in the region of moderate damage with an 80 percent probability of debris formation at the so-called severe damage level. At overpressures greater than 6 psi, thermal effects would tend to predominate and ignition of dry wood poles and trees could reduce the longer term street blockage or debris problem. The above-suggested fractions are intended to apply to open-country highways and roads, streets in residential areas (1-2 story dwellings) and to tree or pole-lines alongside major highways through cities.

For automobiles and small trucks and buses in similar situations, the following fraction damaged (to non-operable or debris-forming conditions) function is suggested:[1]

| | Overpressure (psi) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 14 |
| Fraction Non-Operable | 0.01 | 0.07 | 0.17 | 0.33 | 0.40 | 0.60 | 0.75 | 0.85 | 0.90 |

A surface detonation in the low MT yield range is assumed for the overpressure scale, as in the case of the poles and trees. For thermally unshielded vehicles, the fractions non-operable at 6 psi and greater should be increased by 0.10 to reflect a greater degree of damage and a smaller chance of the vehicle being in driving condition (a burned-off set of tires may not deny the possibility of driving a vehicle to another location, but burned-out wiring insulation would deny it).

An illustrative calculation of debris conditions resulting from destruction of typical residential, commercial, and industrial structures was performed using the assumed conditions that are summarized in Table 9. The calculated average and maximum debris depths and number of

Table 9

Summary of Assumed Conditions for an Illustrative Calculation Using the Described Debris Formation Estimating Relationships

| Item | Wood Frame Dwellings | Commercial Structures | Industrial Structures |
|---|---|---|---|
| $\bar{H}$ (ft) | 20 | 100 | 50 |
| LxW (ft x ft) | 400 x 400 | 300 x 300 | 300 x 200 |
| C | 0.30 | 0.90 | 0.60 |
| S(ft) | 40 | 70 | 80 |
| EBW | 33 | 103 | 44 |
| DF (blast) | 0.22 | 0.40 | 0.35 |
| DF (blast + fire) | 0.026 | 0.20 | 0.20 |
| $\bar{F}_d$ | 0.016 | 0.0083 | 0.0079 |
| H/S | 0.50 | 0.43 | 0.62 |
| Poles/Block | 4 | - | - |
| Trees/Block | 40 | - | - |
| Outside Autos/block | 10 | - | - |

poles, trees, and autos down per block are summarized in Table 10 for locations ranging from 1.9 to 4.7 miles away from a 1-MT yield surface detonation. Results for blast effects only, (B), and for blast plus fire effects (B + F) are summarized. If the incidence of fire in the 2 to 5 psi range is taken to be small, then the results for blast plus fire would be used to the distance of 2.7 miles and the results for blast only would be used in the distance range of 2.7 to 4.7 miles from ground zero. In this case, the largest values of $\bar{d}$ for the wood frame dwellings would be the 0.9 ft value for the 2.7 mile distance. The largest value of $\bar{d}$ for the commercial structures would be about 6 ft at 1.9 mile from ground zero; at the latter distance, $\bar{d}$ for the industrial structures would be about 1 ft.

It is not likely that pneumatic-tired vehicles could travel very long in streets where the debris is 1 inch deep on the average ($\bar{d}$ = .08). Therefore, if a $\bar{d}$ value of 0.1 ft is taken as the limiting level of debris for vehicular travel in the streets, then truck-mounted firefight operations would not be possible at locations nearly ground zero than about 5 miles (1.8 psi) for wood frame dwellings, about 4 miles (2.5 psi) for commercial structures, and about 3 miles (3.7 psi) for industrial structures (each with the respective characteristics given in Table 9). In the residential areas, street blockage by more than about 2 trees or poles per block would probably eliminate movement for all early time emergency operations at distances more than 2 or 3 blocks away from any center. These results suggest that, for most urban areas subject to nuclear attack, vehicular traffic would be severely hindered by debris in areas where the effects of a 2 psi overpressure are experienced and would be effectively stopped in areas where the effects of a 4 psi overpressure are experienced.

## TABLE 10

**Summary of Debris Depths and Damages at Selected Distances from Ground Zero of a Low MT Yield Surface Detonation for Residencial, Commercial, and Industrial Structures**

| | Distance from Ground Zero (Miles)[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Item | 1.9 | 2.0 | 2.1 | 2.3 | 2.5 | 2.7 | 3.1 | 3.6 | 4.7 |
| | | | | 1. Wood Frame Dwellings (B) | | | | | |
| $\bar{d}$(ft) | 0.98 | 0.98 | 0.98 | 0.98 | 0.95 | 0.88 | 0.74 | 0.51 | 0.16 |
| $d_m$ (ft) | 1.0 | 1.0 | 2.0 | 2.9 | 3.8 | 4.4 | 4.4 | 4.6 | 1.8 |
| Poles Down | 4 | 4 | 4 | 4 | 4 | 3 | 2 | 1 | 0 |
| Trees Down | 40 | 40 | 39 | 38 | 36 | 30 | 20 | 1 | 0 |
| Autos Down | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| | | | | 2. Commercial Structures (B) | | | | | |
| $\bar{d}$ (ft) | 12 | 10 | 6.8 | 4.1 | 1.9 | 1.0 | 0.38 | 0.14 | 0.06 |
| $d_m$ (ft) | 12 | 10 | 6.8 | 4.1 | 3.8 | 3.1 | 1.1 | 0.6 | 0.4 |
| | | | | 3. Industrial Structures (B) | | | | | |
| $\bar{d}$ (ft) | 2.2 | 1.8 | 1.2 | 0.73 | 0.40 | 0.18 | 0.07 | 0.02 | 0.01 |
| $d_m$ (ft) | 2.2 | 1.8 | 2.4 | 2.2 | 1.6 | 0.9 | 0.4 | 0.2 | 0.1 |
| | | | | 4. Wood Frame Dwellings (B + F) | | | | | |
| $\bar{d}$ (ft) | 0.12 | 0.12 | 0.12 | 0.12 | 0.11 | 0.10 | 0.09 | 0.06 | 0.02 |
| $d_m$ (ft) | 0.12 | 0.12 | 0.2 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.2 |
| Poles Down | F[b] | F | F | 4 | 4 | 3 | 2 | 1 | 0 |
| Trees Down | F | F | (20)[c] | (30)[c] | 36 | 30 | 20 | 1 | 0 |
| Autos Down | 9 | 8 | 7 | 6 | 5 | 3 | 2 | 1 | 0 |
| | | | | 5. Commercial Structures (B + F) | | | | | |
| $\bar{d}$ (ft) | 6.2 | 5.1 | 3.4 | 2.0 | 1.1 | 0.51 | 0.19 | 0.07 | 0.03 |
| $d_m$ (ft) | 6.2 | 5.1 | 3.4 | 2.0 | 2.3 | 1.5 | 0.6 | 0.3 | 0.2 |
| | | | | 6. Industrial Structures (B + F) | | | | | |
| $\bar{d}$ (ft) | 1.2 | 1.0 | 0.70 | 0.42 | 0.23 | 0.10 | 0.04 | 0.01 | 0.006 |
| $d_m$ (ft) | 1.2 | 1.0 | 1.4 | 1.3 | 0.9 | 0.5 | 0.2 | 0.1 | 0.06 |

[a] Representative distances for a 1-MT yield surface detonation (overpressure of 2 to 10 psi)

[b] Assumed to be destroyed by fire

[c] Estimated (some burned)

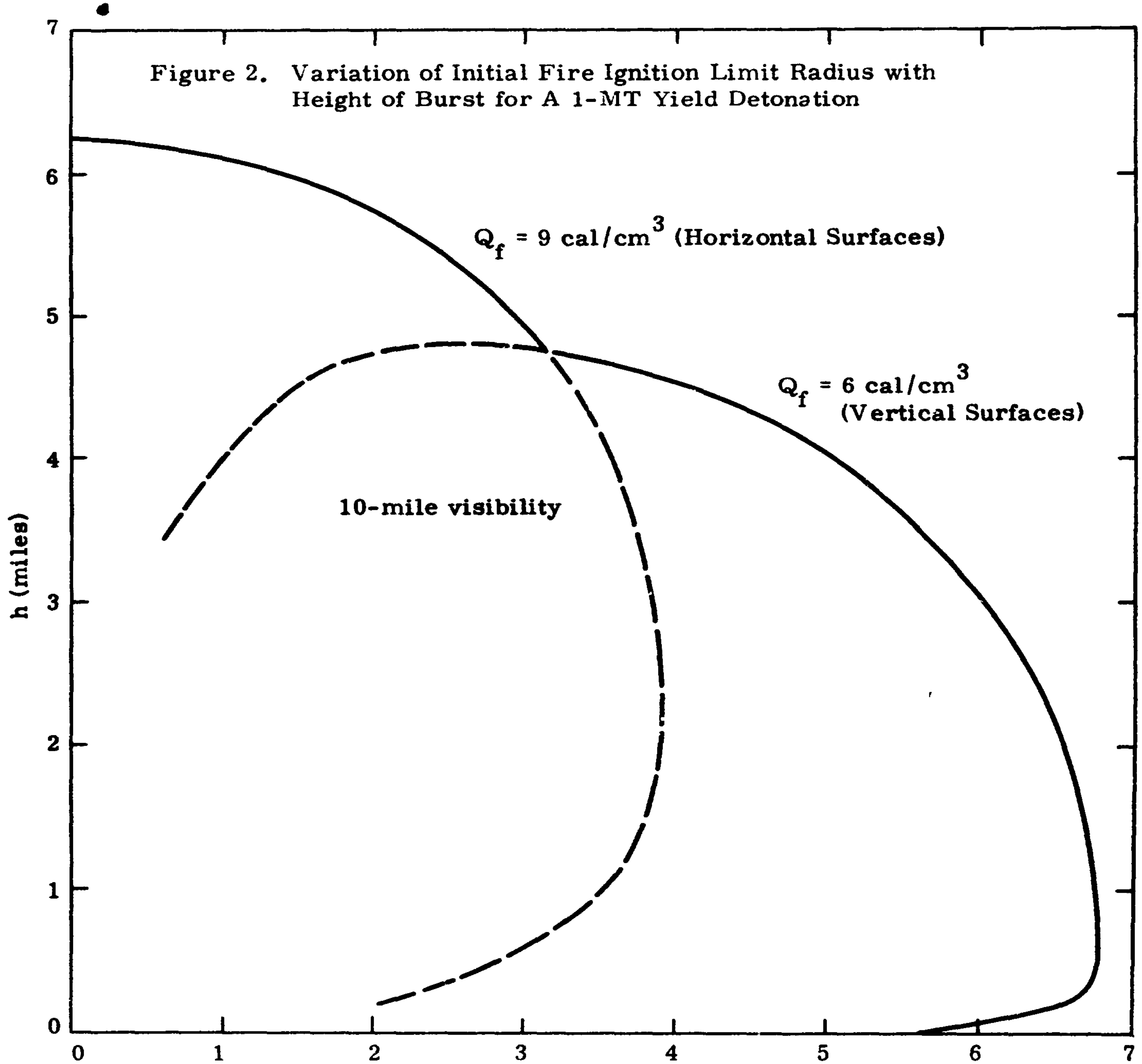
## THERMAL EVENTS

Constraints on the scale of thermal events may be of interest in civil defense operational planning and training, including the preparation of scenarios and guidance materials. These events may be discussed under five different subject areas: (1) fire ignitions or starts, (2) room flashover, (3) fire spread, (4) fire hazards, and (5) countermeasures.

Fire ignitions from nuclear detonations are generally classed as primary or secondary according to whether a fire is caused directly by the thermal effect or secondarily by the blast or shock effect. The limiting range of ignitions in urban areas subjected to thermal and blast effects of a nuclear explosion in the megaton yield range is established by the thermal effect. This is illustrated in Figure 2 in which an initial fire ignition limit radius is shown plotted as a function of the height of burst for a 1-MT yield nuclear detonation. The constraint values of $Q_f$ (the 1-KT equivalent incident thermal energy) were derived from the observed fire perimeter at Hiroshima, Japan; the 6 cal/sq cm refers to an incident energy threshold for the ignition of (colored light) curtains and the 9 cal/sq cm refers to an incident energy threshold for the ignition of dry wood shingles.

The solid-line curve of Figure 2 represents a distance, designated by r, at which the probability of an ignition (leading to a significant fire) goes to zero. No information is provided regarding the probability of fire starts at distances from ground zero less than r. An extreme case of low probability of fire starts is illustrated by the curves shown in Figure 3 in which the probability of a primary fire starts in the interior room of a residential structure as a function of radial distance from a low airburst of a 1-MT yield; the curves are from a reported URS Research Company blast effects considered case study.[7] For the window-covered situation of that study, the probability of fire starts is depicted to be zero in the range of about 3.3 to 4.8 miles from ground zero where the

Figure 2. Variation of Initial Fire Ignition Limit Radius with Height of Burst for A 1-MT Yield Detonation



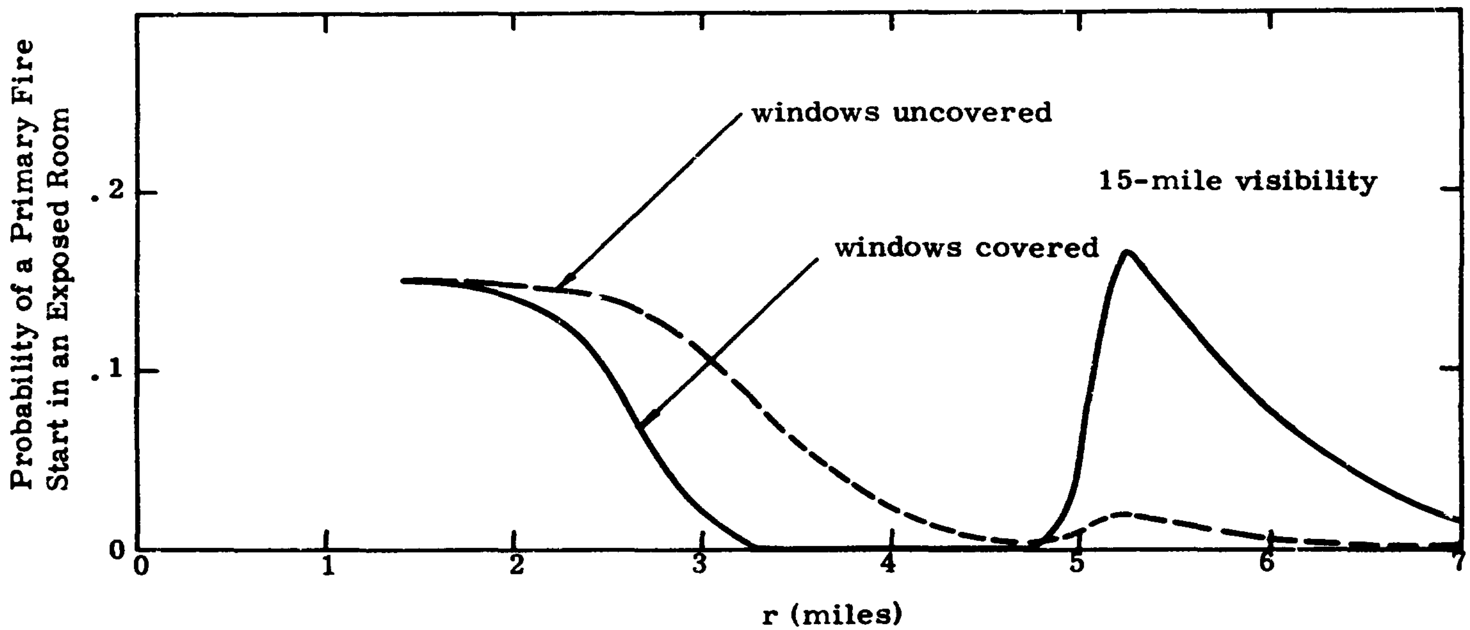



Figure 3. Variation of Primary Fire Starts in Interiors of Residential Structures with Distance from Ground Zero for a 1-MT Yield Low Airburst (URS, Blast Effects Considered)

overpressure ranges from about 2 to 5 psi; the calculational conditions thus includes a statement that the blast wave puts out all primary ignitions in materials of a room so that probability of a fire start is zero. Such a statement, of course, is not a generally true one with regard to total fire starts because secondary fire starts are not considered and it is not quite true with regard to all primary fire starts in rooms of any and all structures (residences or other) because smouldering fuels are not extinguished by the blast wave in the 2 to 5 psi overpressure range. Secondary fire starts should become important in residential areas at distances from ground zero where the overpressure exceeds 2 psi because of damage to wood frame structures.

The relative distances to overpressure contours of 2, 4, and 6 psi and the associated incident thermal energies for a 1-MT yield detonation exploded on a clear day are as follows:

| | Overpressure (psi) | | |
|---|---|---|---|
| | 2 | 4 | 6 |
| Range, surface burst (mi) | 4.7 | 3.0 | 2.6 |
| Height for Max. Range (mi) | 2.3 | 2.1 | 1.7 |
| Max. Range (mi) | 8.0 | 4.9 | 3.8 |
| Q, surface burst ($cal/cm^2$) | 20 - 30 | 40 - 60 | 70 - 80 |
| Q, air burst at height for $r_{max}$ ($cal/cm^2$) | 8 - 12 | 20 - 30 | 40 - 50 |

These distances indicate that the reported URS Research Company calculations most likely are for the surface burst case so that for r values less than 3 miles, severe damage would result to wood frame buildings and the calculated probabilities for room flashover no longer are applicable. If the probabilities of Figure 2 actually are room flashover probabilities, $P_r$, then where applicable ($r \geq 5$ miles), the probability of at least one room flashover per building, $P_B$ is given by [12]

$$P_B = 1 - (1 - P_r)^w \tag{8}$$

where w is the number of windows per building on its exposed side. Thus for an exposure of 5 windows where $P_r$ is 0.15, the value of $P_B$ would be estimated at 0.56. For secondary fire starts, a very approximate estimate of $P_r$ may be estimated from

$$P_r = 0.002\, e^{4.61(p/p_s)} \tag{9}$$

in which p represents the overpressure and $p_s$ represents the overpressure at which severe damage occurs. For these types of fire starts, w represents the number of secondary fire sites per building (e.g., for a house with a gas stove, a gas water heater, and a gas furnace (all with pilot light flames), the value of w would be 3. Thus, for a wood frame structure at $p = p_s$, the value of $P_r$ is 0.2 and the value of $P_B$ (w = 3) would be 0.49. Values of $p_s$ for various building types for detonations with yields near one megaton are listed in Table 11. The values of $p_s$ range from 3.5 psi for wood frame buildings to 22 psi for multistory, reinforced concrete frame office buildings which are earthquake resistant.

For structures that do not sustain moderate damage (rooms and contents remain essentially intact after passage of the blast wave; e.g., at overpressures less than about 2 psi for wood frame structures) and where the ignitions are not extinguished by the blast wave, the time of room flashover, $t_F$, may be estimated from [3]

$$t_F = t_F^{\circ} \sqrt{0.079 - \log f_{PF}} \quad \text{minutes} \tag{10}$$

Table 11

Summary of Maximum Range and Overpressure at which Severe Damage to Different Building Types Occurs Following a 1-MT Yield Airburst

| Building Type | Range (mi) | Overpressure($p_s$) (psi) |
|---|---|---|
| 1. Wood frame | 5.3 | 3.5 |
| 2. Multistory, wall bearing, brick apartment | 3.8 | 6.0 |
| 3. Multistory, wall bearing, monumental | 2.8 | 10.0 |
| 4. Multistory, reinforced concrete, concrete walls | 2.7 | 11.0 |
| 5. Multistory, reinforced concrete, frame (office), earthquake resistant | 1.6 | 22.0 |
| 6. Light steel-frame, industrial | 2.7 | 10.5 |
| 7. Heavy steel-frame, industrial (25-50 ton crane) | 2.5 | 12.5 |
| 8. Heavy steel-frame, industrial (60-100 ton crane) | 2.2 | 15.0 |
| 9. Multistory, reinforced concrete frame (office) | 2.1 | 16.0 |
| 10. Multistory, steel frame (office) | 1.9 | 18.5 |

in which $f_{PF}$ is the fraction of primary fire starts with room flashover times no greater than $t_F$ and $t_F^\circ$ is a constant whose value depends on the types of room content fuels. Typical values of $t_F^\circ$ are as follows:

$t_F^\circ$ = 26.3 min. for fires from ignition of conventional upholstery

$t_F^\circ$ = 11.3 min. for fires from ignition of foam rubber upholstery

$t_F^\circ$ = 13.9 min. for fires from ignition of box spring mattresses

$t_F^\circ = \infty$ min. for fires from ignition of open coil spring mattresses

The value of infinity for $t_F^\circ$ (open coil spring mattresses) indicates that no room flashover would result from such ignitions and that no fire spread to other rooms would be indicated. For the other 3 cases, the limiting room flashover time for 50 percent of the fire starts would be about 10, 7, and 9 minutes, respectively for rooms with conventional upholstered furniture, foam rubber upholstered furniture, and beds with box spring mattresses.

The progress of fires in structures after (the first) room flashover has been expressed in terms of a volume fire spread function given by[13]

$$V_t = V_o \, e^{(t - t_F)/m} \qquad \text{cu/ft} \qquad (11)$$

in which $V_t$ is the volume of compartments (rooms) in flame at the time after first ignition, t, $V_o$ is the volume of compartments (rooms) in flame at $t_F$, and m is constant whose value apparently depends on the type of structure and contents and on the ambient wind speed. If a structure contains $m_R$ rooms which are all approximately the same size, then the time after ignition, $t_n$, when $n_R$ rooms are in flame would be given by

$$t_n = t_F + 2.303\, m \log n_R \qquad \text{minutes} \qquad (12)$$

For the progress of fires started in one room of simple one-story (plus attic) wood frame structures, the dependence of the parameter m on wind speed may be approximated by[13, 24]

$$m = 5.91\, e^{-0.00259 v^2} \qquad \text{minutes} \qquad (13)$$

for v in mi/hr. For large commercial buildings with about 25 $lb/ft^2$ of fuels on each floor, the fire spread rate is estimated to be considerably slower than for the wood frame structures, with an average radial spread rates on a floor of about 1 ft/min. Approximate spread rates upward to adjacent floors may be estimated from[10]

$$t_{n-n_o} = 75 + 149 \log (n + 1 - n_o) \text{ minutes} \qquad (14)$$

in which $n_o$ is the floor at which the initial fire starts and room flashover takes place, n is any other (higher numbered) floor, and $t_{n-n_o}$ represents the time at which the contents and structural parts of the entire nth floor are in flame. For fire spread to lower floors, the time at which the whole nth floor is in flames may be estimated from[10]

$$t_{n_o-n} = 75\,(n_o + 1 - n) \qquad \text{minutes} \qquad (15)$$

The effect of wind speed and other factors on $t_{n-n_o}$ and $t_{n_o-n}$, if any, are unknown. Typical values of these times for select values of $n - n_o$ are as follows:

| $n - n_o$ | $t_{n - n_o}$(min) | $n - n_o$ | $t_{n_o - n}$(min) |
|---|---|---|---|
| 0 | 75 | 0 | 75 |
| 1 | 120 | -1 | 150 |
| 2 | 146 | -2 | 225 |
| 3 | 165 | -3 | 300 |
| 4 | 179 | -4 | 375 |
| 5 | 191 | -5 | 450 |

The functions of Equations 14 and 15 allow 75 min for spread of the fire through the floor of origin, a constant downward rate of spread, floor-to-floor, and an increasing rate of floor-to-floor upward spread. The values of the burning times for Equations 14 and 15 assume no effect of fires in debris that may be piled up in adjacent streets. Many of the larger and heavier commercial buildings would suffer severe damage only if subjected to overpressures in the range of 10 to 20 psi; however, debris pile-up in the street from building contents, doors, windows, and weak curtain walls can be expected to become significant at overpressures in the range of 6 to 12 psi (at an overpressure that is about 60 percent of the overpressure for severe damage - see previous discussion on debris formation). Fire in the debris could be expected to spread to the lower floors of adjacent buildings and thence upward at rates indicated by Equation 14 until it met the fires proceeding downward.

Estimated probabilities for ignitions in high-rise buildings such as in the Chicago loop area are shown as a function of number of windows and floors in Figure 4 for a 5-MT yield surface detonation at a range of 5 miles from the center of the area. The expected number of ignitions in a building is shown in Figure 5 and the probability of ignition(s) in buildings of different heights is shown in Figure 6.[10] The fact that most (primary) ignitions are on the upper floors is because the tall buildings shield the lower floors from direct exposure to the thermal pulse. The fraction of floors that would be in flame at various times after the initial

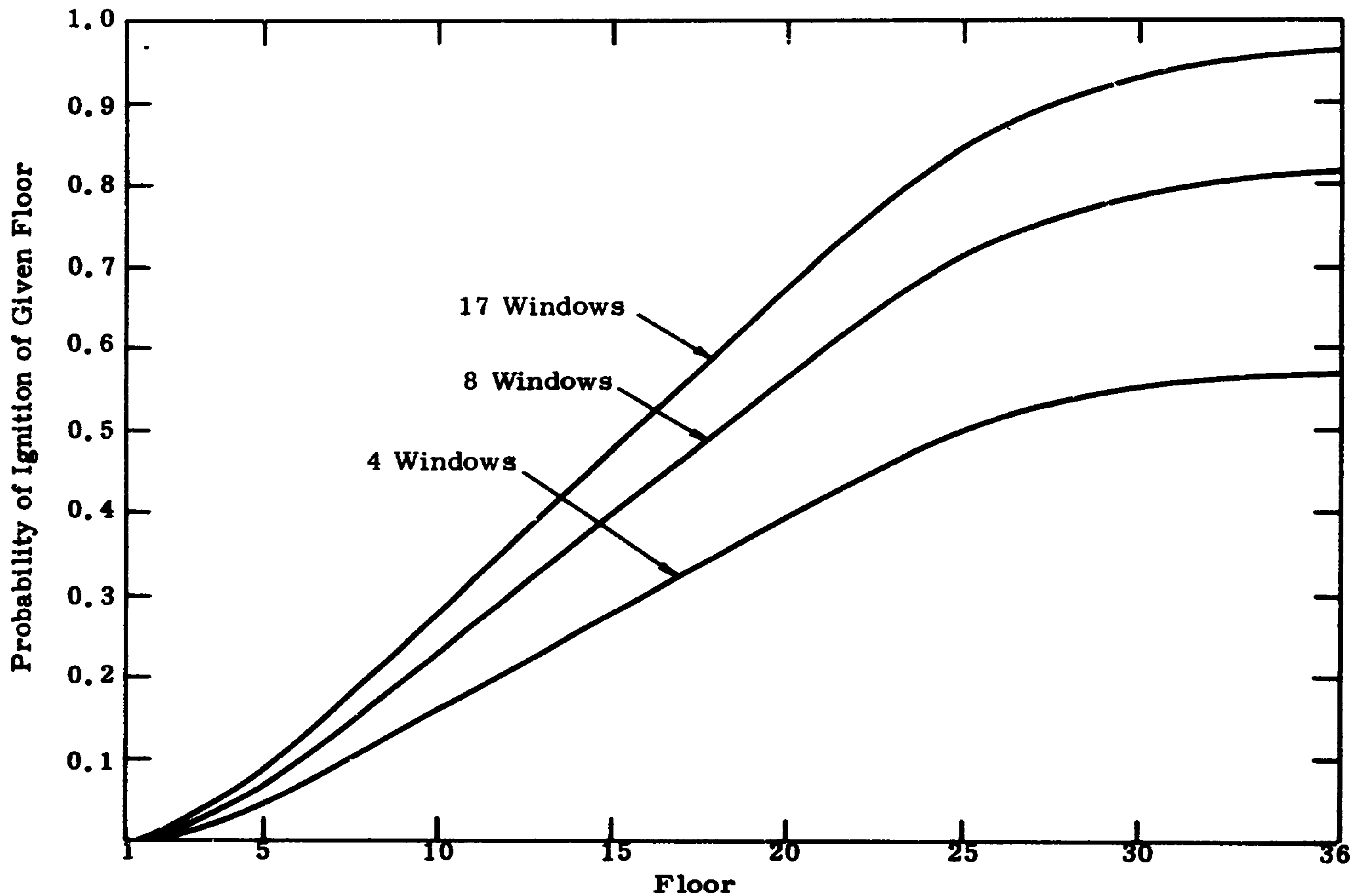



Figure 4. Estimates of Probability of Ignition of Different Floors

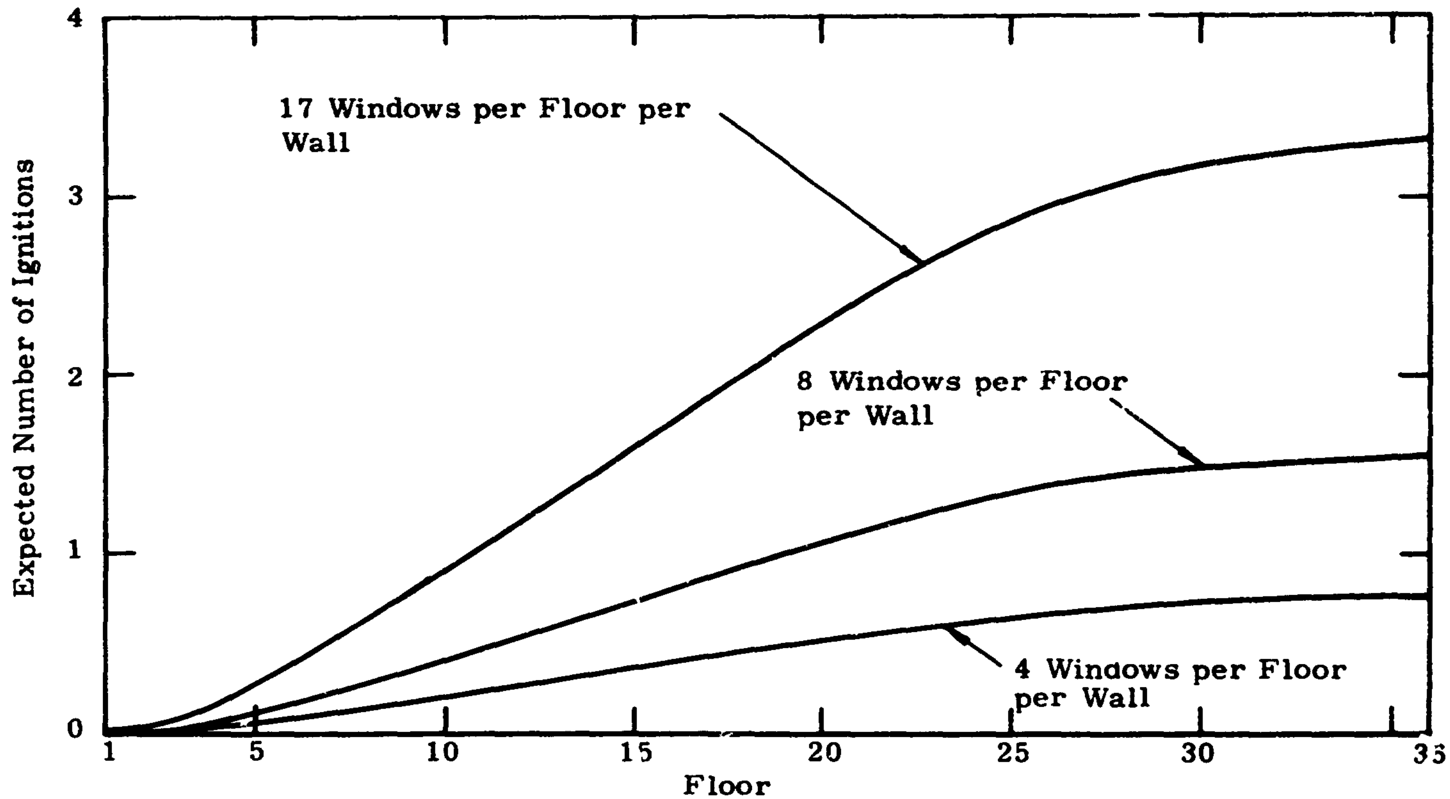



Figure 5. Estimates of Expected Number of Ignitions on Given Floors of Building

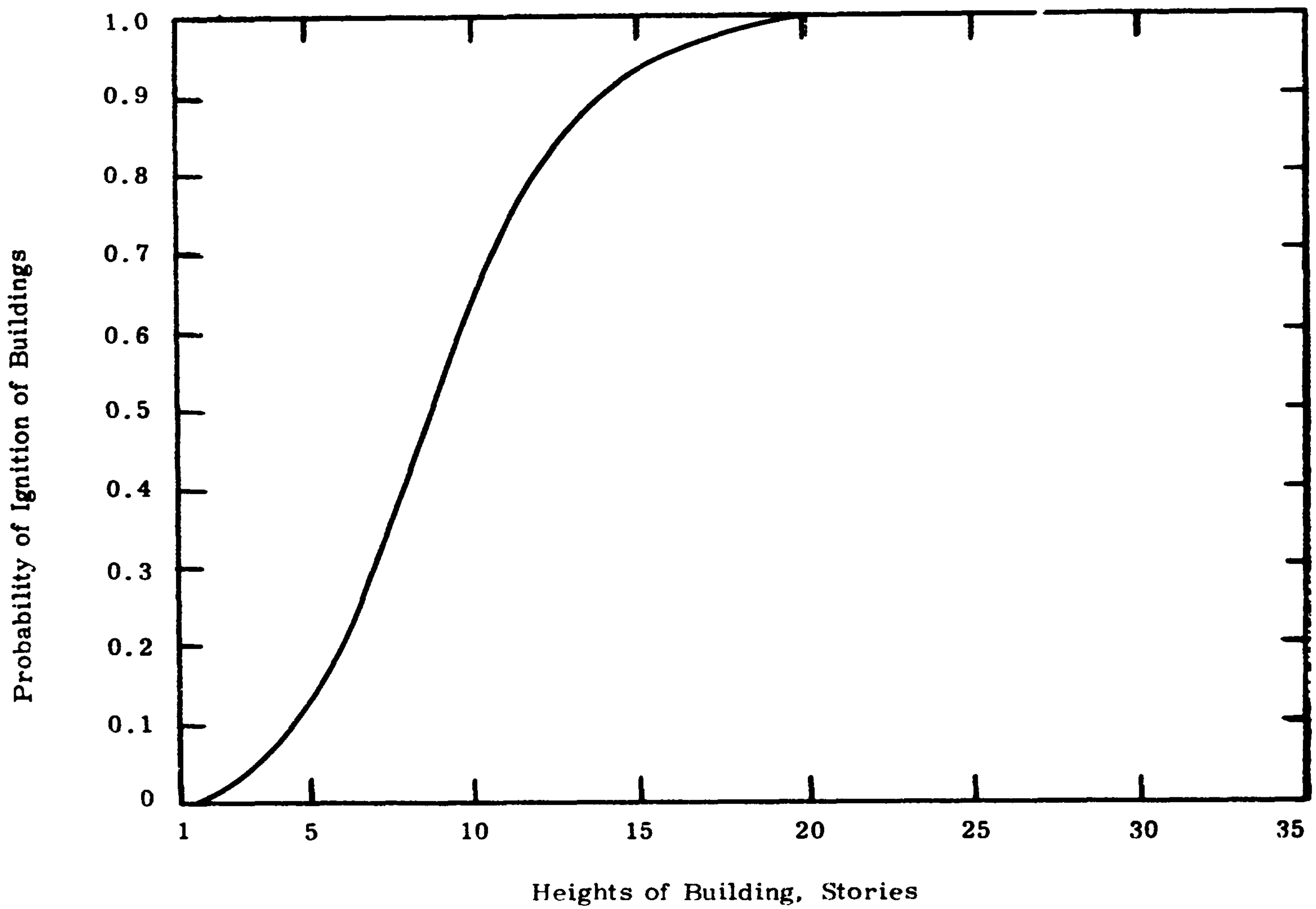



Fig. 6 Estimates of Probability of Ignition of Buildings of Different Heights

fire starts, distributed as indicated in Figures 4 through 6 is shown in Figure 7; the calculations assume no effect of possible debris fires.

The peak intensity of fires in simple one story single wood frame structures usually occurs within about 30 minutes after fire ignitions; observed times of peak intensity, $t_m$, tend to decrease as the ambient wind speed increases. Structural damage appears to cause a decrease in $t_m$ as well as in the magnitude of the peak intensity. Approximate values of $t_m$ for a fire in a single, small slightly damaged or undamaged wood frame building for a given ambient wind speed, v, obtained from the equation[13, 14]

$$t_m = 26\, e^{-0.0246 v} \tag{16}$$

For partially damaged structures and smaller compacted structures (1000 sq ft area or less), the coefficient of Equation 16 is reduced from 26 to 21. Peak radiation intensities in the streets from fires in high rise buildings (Chicago loop case) are shown as a function of time after detonation in Figure 8 for the case of no debris fires. The time of peak intensity is shown to occur in the period of 3 to 4 hours after ignition of the fires. However, the time of peak intensity at the level of the fires in the upper stories would be expected to occur between 1 and 2 hours after ignition (i.e., shortly after the contents of one full story is aflame).

In the periphery of the damage area to which the above-presented fire-events and descriptions apply, the single fires could spread until they coalesce to form a large area mass fire; or, they could burn out without further spread. Fire spread and ultimate fire damage depend on building density, especially for the case where the buildings sustain only light damage. Data from World War II fires suggest that the fraction of buildings, $f_B$, located in an area fire which are destroyed by fire depends on the fractional building density, B, (fraction of area covered by structures) according to[6]

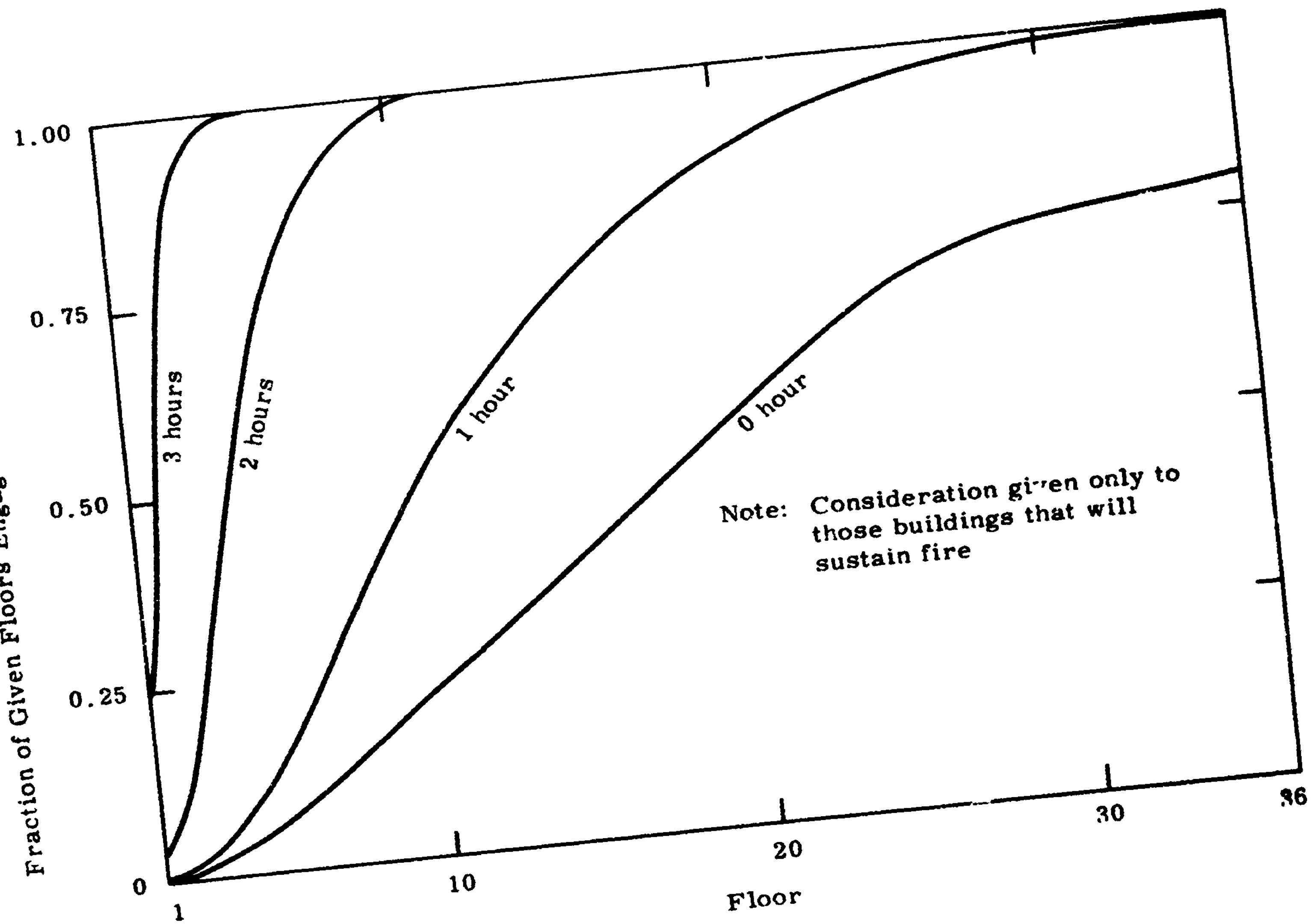



Fig. 7 Estimates of Fraction of Floors Engaged by Fire Assuming Negligible Debris Fires

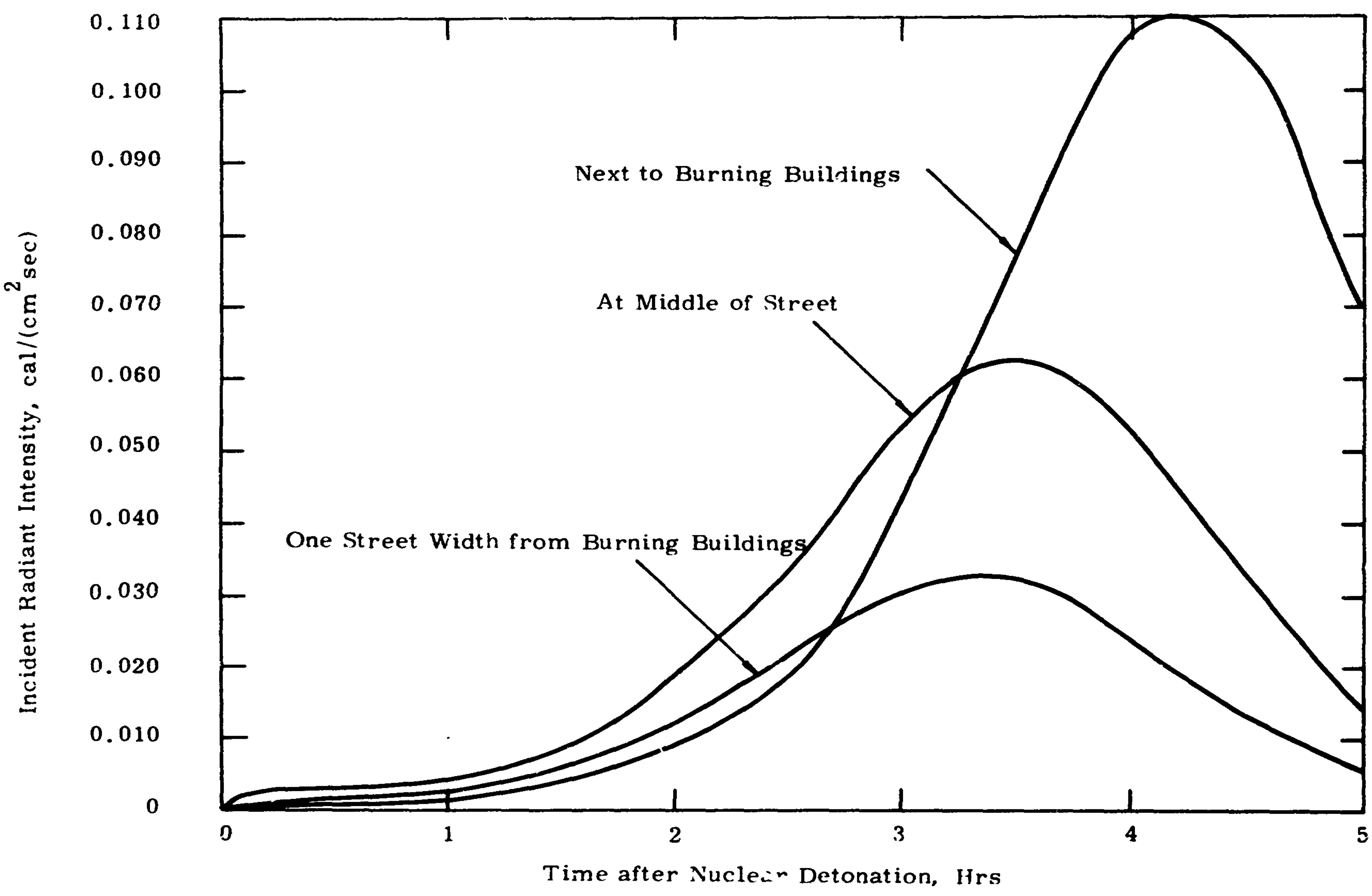



Fig. 8 Estimates of Radiant Intensities in Street Assuming Negligible Debris Fires in Street

$$f_B = f_B^{\bullet} B^x \tag{17}$$

Values of $f_B^{\bullet}$ and x for Equation 17 for structures of various use classes are listed in Table 12; B values for 100 percent destruction of the buildings by fire are 0.59, 0.95, 0.79, and 0.68 for residential, manufacturing, commercial, and transportation and storage use-class structures, respectively.

Table 12

Empirical Values of $f_B^{\bullet}$ and x in Equation for Structures of Various Use Classes

| Structure Use Class Area | $f_B^{\bullet}$ | x |
|---|---|---|
| Residential | 1.9 | 1.2 |
| Manufacturing | 1.1 | 1.8 |
| Commercial | 1.4 | 1.4 |
| Transportation and Storage | 1.6 | 1.2 |

Uncontrollable fires generally spread until they reach a barrier or fire-break of some kind. Data on the fraction of times fires jumped or spread across an open space of distant y, obtained from measurements taken on attacked German cities in World War II and from measurements following the atomic bomb attacks on the Japanese cities of Hiroshima and Nagasaki, are represented very accurately by[6, 15]

$$P_f(y) = e^{-0.014(y-3)}, \quad y \geq 3 \tag{18}$$

in which y represents the firebreak width in feet and $P_f(y)$ represents the probability that a building across the firebreak will ignite. Equation 18 is based on a large number of observations without reference tc weather

conditions, structure type, etc. For a 0.5 probability of fire spread across an open space, y is 52 feet. Measurements of wood ignitions at the Camp Parks, California, burning of simple wood frame structures give ignition probabilities, presumable for radiation and/or convection, that are represented reasonably well by[13, 14]

$$P_f(y, v) = e^{-k(v - v_o)} \tag{19}$$

in which v is the wind speed in mi/hr and in which

$$k = 1.04 \times 10^{-7}(y - 8)^5 \text{ hr/mi} \tag{20}$$

and

$$v_o = 0.079/k \qquad \text{mi/hr} \tag{21}$$

and y is the distance from the exterior of the building in feet. Values of k and $v_o$ for selected values of y are as follows:

| y (ft) | k(hr/mi) | $v_o$(mi/hr) |
|---|---|---|
| 10 | $3.3 \times 10^{-6}$ | $2.4 \times 10^4$ |
| 20 | 0.026 | 3.1 |
| 23 | 0.079 | 1.0 |
| 30 | 0.53 | 0.15 |
| 32 | 0.82 | 0.10 |
| 50 | 1.35 | 0.06 |

The distances of travel for fire brands was also observed in the Camp Parks fire investigations on wood frame structures; the data for the larger brands, after adjustment to Equation 18, may be represented approximately by

$$P_f(y) = e^{-0.693(y-3)/(y_{50}-3)} \quad (22)$$

where

$$y_{50} = 20.6\, e^{0.184v}\ \text{ft}, \quad v < 13\ \text{mi/hr} \quad (23)$$

and

$$y_{50} = 37.5(v-7)\text{ft}, \quad v \geq 13\ \text{mi/hr} \quad (24)$$

Thus if the major mechanism for firespread was sparks and firebrands for the events which provided the data which are represented by Equation 18, then the average ambient wind speed for that data was about 5.1 mi/hr. In most cases, the wood ignitions and heaviest firebrand deposits described by Equations 19 through 24 occurred at times near $t_m$; thus the rate of fire spread by these mechanisms is initially controlled sequentially by the time at which maximum intensity occurs for the various burning structures.

The rapid coalescing of fires and build-up often reported for mass fires (i.e., 30 minutes) is, in the context used, an exaggeration for a mass fire but probably in most cases would be applicable to an isolated structure as described above. In the large fires of World War II, such as for Hamburg, the time for isolated or single unit fires to spread and grow into row or block fires was more like 3/4 to 1 hour and the rapid spread and coalescence to form an area fire did not take place until the second hour after bombardment ceased. The firestorm in Hamburg reached its high point in the period of 2 to 3 hours after bombardment and the fires subsided appreciably after a period of 4 to 6 hours after bombardment. The crisis period thus ranged from about 2-1/2 to 5 hours after attack (an overall intense fire duration of around 2-1/2 hours but which was more nearly a duration of 1 to 2 hours at specific sites within the area of burning).

In areas of appreciable street debris and rubble for the Hamburg fires, the surface fuels burned fairly rapidly but not with the intensity of

the standing structures with broken windows and doors. The buried fuels burned for periods of several (2 to 4 days) days and could only be extinguished by prolonged and repeated spraying with lots of water. The spread of fires from one pile of debris to another was not mentioned in official reports, probably because it was inconsequential relative to that for the burning buildings. No firefighting was ever accomplished by the professional units of Hamburg in areas where appreciable debris covered the streets and no fire fighting was ever successfully accomplished at locations within the region of the area fires.[11, 15, 18]

According to measurements of temperature and CO in compartments during the fires at Camp Parks, California, the first time at which a critical hazard condition developed, generally was very close to the time of room flashover of the partially damaged or undamaged structures. Most of the critical hazard conditions related to lethality which did develop were for thermal effects. However, in view of the length of time generally observed for the build up of fire intensities in buildings and areas, prompt action as needed should make possible the safe exit of all persons from fire susceptible areas, except those who might be trapped by debris. The critical period for initial action would be for those who might be positioned in rooms subject to ignition starts and room flashover where blast effects are not sufficiently severe to put out the primary ignitions or to produce more than slight damage to the structure.

In Nagasaki, Japan, where many persons were injured by both blast and thermal effects, deaths among them occurred over an extended time period; the accumulated fraction up to a time, $t$, after attack of immediate survivors, $F_{sd}$, who eventually died is approximated by[16]

$$F_{sd} = 1 - e^{-0.067(t - 1.6)} \tag{25}$$

where t is in days after attack. Thus 50 percent of the injured that eventually died did so within about 12 days after attack.

While various thermal countermeasures may be put into practice prior to a nuclear attack, the first, and perhaps only, opportunity to retard and control fires started by a nuclear attack occurs during the time period prior to first room flashover in the peripheral regions of the damaged area. Actions by self-help or professional units in this period of time is usually termed ignition suppression. The limiting time for effective application of fire suppression actions has been suggested to be within 2 minutes of room flashover (i.e., $t_f - 2$). Limiting times at the 50 percent occurrence time of room flashover would be about 14 minutes after attack for rooms with conventional upholstery in furniture, about 5 minutes for rooms with foam rubber in furniture, and about 7 minutes after attack for bedrooms in which the beds have innerspring mattresses.

In regions of the damage area that are subjected to over pressures in the range of 2 to 5 psi, the blast wave may extinguish all flames but not smouldering combustion in the above-mentioned fuels. Smouldering combustion in these fuels continues until conditions are reestablished for flaming combustion. The delay period for re-ignition has been observed to range from about 20 minutes to several hours. Since smouldering combustion may be decreased by dust produced by blast damage to walls and other objects, the delay time for re-ignition and room flashover should be approximately proportional to the square of the overpressure; a rough approximation might be that given by[7, 9]

$$\Delta t_F = 0.1\, p^2 \quad \text{hours,} \quad p < p_s \tag{26}$$

Thus at an overpressure of 3 psi where wood frame structure would begin to suffer severe damage, the re-ignition delay time would approach 1-1/4 hours. However, at higher overpressures, the secondary ignitions would be the more significant ones for initiating fires in the debris and the remains of severely damaged structures. The delay due to flame suppression by the blast wave thus would permit more effective application of self-help firefighting techniques for smouldering fuels. The delay times could

probably be significantly increased by preattack use of heavy window coverings which would further depress the frequency of primary ignitions in smouldering fuels (assuming that the blast wave would extinguish all flames in the window coverings).

World War II experience in Germany showed the relative effectiveness of properly organized self-help forces in extinguishing fire bomb ignitions prior to room flashover. Until the self-help forces were effectively disbanded by evacuation orders, the self-help firefighting forces of Hamburg fought 59 percent of all fires, even though they operated only on small fires. They were not trained nor equipped to cope with fires beyond the point of first room flashover. The peak capability of the self-help units (3-man teams were the most effective) averaged 2 fire sites per attack. This suggests that there exists an upper limit in the number of fire sites that could be attended by one such team during a nuclear attack except for the events where a delay in flame ignition of the smouldering fuels would allow the extra time that would be needed for a team to put out additional smouldering combustion fires.[15, 18]

The professional firefighting forces of Hamburg, Germany, fought fires at the maximum average rate of 6 fire sites per squad per attack; they had alternate water sources available to them for fighting fires. The municipal water system failed early in all major air attacks on the city. Water requirements for firefighting, based on Hamburg experience prior to the large scale air attacks 1943, is represented approximately by[15]

$$V = 0.22(E)^{1.5} \text{ cubic meters} \qquad (27)$$

where E is the effort in man-hours per fire site spent in containing or extinguishing the bomb-caused fires. The mid-frequency (50%) effort level used in fighting various types of fires, excluding conditions where mass fires occurred, were as follows:[15]

| Type of Fire | E(man-hours/fire site) |
|---|---|
| Residential Building Roof and Attic Fires | 9 |
| Single Residence Fires | 51 |
| Several Residences on Fire | 79 |
| Industrial and Office Building Fires | 29 |

For firefighting in the peripheral zone around the areas containing the mass fires in Hamburg, the mid-frequency of the level of effort of the firefighting squads was expressed more according to objective, as follows:

| Type of Action | E(man-hours/fire site) |
|---|---|
| Extinguished fires in Industrial and Office Buildings | 18 |
| Extinguished fires in Residential Bldgs. | 18 |
| Prevented fires in Industrial and and Office Bldgs. from spreading | 27 |
| Prevented fires in Residential Bldgs. from spreading | 16 |

After numerous difficulties with pre-World War II professional firefighting doctrine and tactics, a revised set of guidelines were promulgated by the Hamburg Fire Police. Some of these which would be applicable to many urban fire control situations and to the use of firefighting forces following a nuclear attack on modern cities are as follows:[11]

- Fires in burning buildings are to be fought only when human life is in danger or when danger of fire spread to a nearby building exists.

- Within fire regions where the saving of human lives is of utmost importance, provide rescue assistance including water protective curtains for the escaping persons and lead them to places of safety before resuming fire fighting operations.

- Fight only those fires for which a reasonable chance exists for extinction or confinement in the prevention of further fire spread.

- Wherever possible, fight fires from the inside of buildings where the water jet can be more readily targeted directly on the burning materials; while in burning building be constantly aware of the possibility of collapse of ceilings and walls.

- Fire fighting from outside of buildings is recommended only for fighting certain industrial fires, for containment of area fires, and for control of fires in heaily damaged buildings; fire fighting from the outside requires a large supply of water.

- Fire fighting at burning industrial buildings from the outside is permissible to preserve and prevent thermal deformation of valuable machinery and equipment.

- Shorten the period of deployment of the professional fire fighting forces at industrial fires by deploying civil defense self-help forces to the largest extent possible as fire watches and fighters in the final stages of extinguishment or confinement of a fire.

- Tactically: (1) make a rapid reconnoiter and assessment of the fire threat in the area; (2) move fire-fighting forces rapidly to the damaged area; (3) select fire sites and methods to be used in the fire control mission; and (4) deploy forces rapidly to fire sites and allocate water supplies conservatively to the respective groups.

Combination of the above-summarized fire events and their dynamic constraints, their hazards, and the countermeasure efforts should provide inputs that will be helpful in planning and educating civil defense managers on fire problems that would arise in various situations following a nuclear attack on an urban center.

## HAZARD SITUATIONS AND COUNTERMEASURES OPTIONS

To facilitate a discussion regarding appropriate options of civil defense countermeasures operations it is convenient to consider separately broad categories of hazard and degree of hazard in terms of constraints on operations of all kinds.[3] For example, some areas of the country may experience no direct weapon effect nor any fallout; such areas have been termed FREE areas since no constraint on movement within the area due to weapon effect (blast and thermal) but could receive fallout deposits in varying amounts. And locations near the ground zeros of nuclear explosions would experience the direct effects, with or without fallout depending on burst height and relative locations of several detonations. The regions that would experience the blast and thermal effects, as discussed above, constitute the so-called Damaged Areas.

It has been noted that, depending on the intensity of a direct effect (e.g., blast overpressure) and the characteristics of a target area, civil defense operations may at some stage be limited by the consequences (e.g., debris in streets). To accommodate such changes among situations and options in a systematic set of descriptive classifications, it is convenient to divide the situations or effects into 3 levels of severity or intensity and consider all combinations; thus the fallout hazard situations may be considered in terms of a no hazard (NF), a moderate hazard (MF), and a severe hazard (SF). Similarly the damage situation, without specification initially as to being blast-caused or fire-caused, may be considered in terms of no hazard (ND), moderate hazard (MD), and severe hazard (SD). These terms are matricized as follows with the combinations being numbered 1 through 9:

| | ND | MD | SD |
|---|---|---|---|
| NF | 1 | 4 | 7 |
| MF | 2 | 5 | 8 |
| SF | 3 | 6 | 9 |

In the matrix, situation No. 1 refers to the FREE area condition mentioned above. Some general descriptions of the various other combined situations are discussed below along with a few associated applicable countermeasure options for each.

2. Moderate Fallout, No Damage

This is a fallout-only hazard situation where extended shelter occupancy would be required due to the presence of moderate levels of fallout. After the radiation intensity decays for a few days, the area situation converts to a Free (NF, ND) Area situation with little or no restriction on movement or on other out-of-shelter activities due to fallout effects. Thus the major countermeasure is to stay in shelter for the appropriate length of time (say, 7 days).

Principal countermeasures for areas with moderate fallout are:

(1) Occupy available shelter; for the bulk of the population, shelter occupancy would continue until the radiation intensity decreased by decay to the point at which the change to FREE Area conditions takes place.

(2) Conduct short-term outside operations when the exposure rate decreases to a permissible level; major operations for decreasing shelter stay time beyond two weeks for $I_s$ levels of about 1,500 R/hr at 1 hr or greater would be decontamination of vital facility working areas and living quarters.

(3) Evacuation to nearest FREE area staging locations when appropriate.

(4) Entry of mobile forces from FREE areas for short term operations (supply of shelterees, operation of vital facilities, or decontamination operations) to assist in recovery of economic resources.

3. Severe Fallout, No Damage

This is a fallout-only hazard situation where the fallout levels would be sufficiently high to exceed the radiation sickness threshold dose for some

people in shelters and where, in some areas and shelters, the radiation fatality threshold dose would be exceeded.

Remedial movement assistance from task force elements of nearby areas with moderate and low fallout levels to alleviate situation is one countermeasure option. However, such assistance would have to be effective prior to the time when the exposure (dose) of the shelter occupants reached 150 roentgens. Other (mostly unevaluated) countermeasure alternatives include:

(1) Evacuate to shelters in nearby areas with moderate fallout levels or to the more remote "free areas".

(2) Decontaminate an area around the shelter (i.e., the possibility of an overexposure of a few).

(3) Prior installation of automatic decontamination devices (roof-washdown, blowers, removable roof and area cover, etc.).

(4) Provide additional shielding.

(5) Perform special measure (e.g., excessive crowding in most shielded locations of the shelter).

Future damage assessment studies should include procedures for estimating the relative extent of heavy fallout areas as a function of the type and weight of assumed attacks. Estimates of the conditions under which the various action alternatives for the fallout from a single detonation are easily accomplished but are not realistic; the relative influence of overlapping fallout depositions is needed to indicate the feasibility of several of the alternatives.

As defined, a segment of the population in the heavy fallout areas would become radiation casualties or fatalities in due time, and with few exceptions, could not be counted as part of the labor force for either trans-attack or early postattack operations. Most, after evacuation to moderate fallout areas or to "Free" area reception centers, would require medical treatment and care until they either recovered or died.

5. Moderate Fallout - Moderate Damage

This situation category includes those areas in which physical damage from blast or fire effects varies from that which is essentially negligible (broken glass or an occasional fire) to the combined blast and fire effects on the target area that produce sufficient debris to deny vehicular operations without prior debris removal operations. The shelter and shelter occupancy requirements for the moderate fallout shelter are given above.

In affected areas of this kind, both controlled and uncontrolled large-scale mass fires could occur depending on the susceptibility of structures (or other fuel sources) to fire and the effectiveness of the fire-fighting forces. As described in a previous section, the outer perimeter of the moderate damage area (irrespective of the radiological hazard component) for urban centers would be approximately coincident with the distances to overpressures ranging from 2 to 4 depending on the type of structures present. For some air bursts, the outer perimeter could be determined by the maximum range of significant fire ignitions, whenever atmospheric conditions are favorable. Similarly, the inner boundary of the moderate damaged areas generally would be approximately coincident with the overpressure contours ranging from 4 to 6 psi. These specifications are somewhat arbitrary since they imply that vehicular movement would be restricted according to overpressure contour irrespective of target response; however, the primary definition clearly indicates that the nature of the target area would definitely be involved in determining where the actual constraints on operations would take place.

Further detailed analysis of debris conditions as a function of target area characteristics and the potential for vehicular type operations are needed to improve the situation descriptions and the means for identifying the limiting conditions from observable or measureable quantities (e.g., the debris type and depth, or the overpressure) and from prior knowledge of building type (and size) and area density (builtupness).

Major transattack countermeasure operations in the affected areas would include:

(1) Fight fires by ignition suppression.

(2) Evacuate to peripheral areas if ignition suppression efforts are not successful within 10 to 20 minutes after detonation and if the shelter(s) is located in a fire-susceptible area.

(3) Remain in shelter if ignition suppression efforts are successful or if the shelter(s) is located in a firesafe area. (Self-help fire fighting groups return to a shelter location on completion of fire suppression operation.)

(4) Relocate shelters to fireproof shelters or buildings.

(5) Rescue trapped and injured survivors.

(6) Provide first aid and emergency medical treatment to injured.

Further investigation and data are needed on the possible time sequence of the transattack countermeasures and possible requirements for debris removal and other operations prior to the time that a change to the low fallout hazard situation occurs. It is not likely that mobile professional firefighting units would be in operation at 15 minutes after detonation and that, if such units were otherwise in operation at the time, they probably would cease operations when fallout from upwind detonations began to arrive (except for fighting fires in shelters and rescue operations). But as noted elsewhere, the density of debris would tend to limit movement of forces in urban areas where structures suffered moderate damage.

The radiological hazard situation could not be determined until after the time of fallout cessation (unless suitable fallout predictive capabilities are available and in operation at the time with a capability to forecast the dynamic aspects of fallout deposition using wind data, fallout arrival time and exposure rate data measured at other locations, and

available estimates of weapon yield). Improvements in procedures and in input data for forecasting fallout relative to this particular application should be emphasized in future research on the fallout process.

If requirements for debris removal would arise prior to the time that a change to the lower fallout hazard condition occurs, then the exposure dose of the debris removal teams would have to be taken into consideration in planning such an operation. Under these circumstances such operations would, in many instances, be a combined decontamination-debris removal operation. At this time, essentially no research information has been developed for such an operation. Actually, little factual operationally important information on the constraints for other operations, transattack or postattack, (e.g., rescue, evacuation, emergency medical treatment, damage control, and damage repair) have been developed for the areas that would receive moderate damage as well as moderate levels of fallout.

Postattack operations in moderately damaged area would certainly involve debris removal operations (for routes and sites) as well as salvage operations and repair of needed facilities. In cases where an early resumption of services or production is indicated (e.g., a water supply and purification plant, an electric power generating facility, a food distribution center, etc.), site decontamination operations might be required in a moderate fallout hazard situation.

Perhaps the first major decision regarding postattack recovery operations in urban areas that suffered moderate (or heavier) damage would be on whether to evacuate all survivors to the nearest areas lower fallout and damage hazard situations (possibly, with intent to recover and reoccupy the area at an unspecified later time) or to stay and attempt an earlier recovery of the whole area of moderate damage (irrespective of zonal coverage). A decision of this nature would probably require input information from a fairly large region so that it would be based on state or regional conditions as well as on the individual local or zonal situation.

Thus the postattack countermeasure options should incorporate future considerations into the action decisions in addition to those required to alleviate immediate problems and hazards.

Several postattack countermeasure and recovery operational alternatives include (zonal to national level):

(1) Inventory and assessment of population status.

(2) Inventory and assessment of damage to facilities and physical resources (destroyed, salvageable, repairable, undamaged).

(3) Assessment of food, water, housing (shelter), medical, and other survival requirements.

(4) Evacuate survivors to areas with lower hazard situations.

(5) Decontaminate vital areas.

(6) Remove debris from routes and vital areas.

(7) Operate vital facilities.

(8) Repair vital facilities.

(9) Reconstruct vital facilities.

(10) Salvage equipment and supplies.

(11) Allocate resources (supplying, feeding, rationing, controlling, etc.).

(12) Bury the dead.

(13) Recover or provide sanitation facilities.

(14) Provide medical assistance.

(15) Reconstitute governmental functions (including law and order, etc.).

(16) Establish and operate staging areas as needed (to provide temporary housing, to provide interim medical assistance,

to provide organizational and operational control of recovery operations in a region, etc.).

(17) Re-initiate social and financial functions (schools, churches, money, banks, retail stores as pertaining to the private or non-governmental sectors).

Other, and perhaps more comprehensive lists of postattack countermeasure or recovery actions have been prepared. The above list of 17 types, however, should suffice as an illustration of the kinds of post-attack operations that need to be considered for urban areas (especially) exposed to both physical and radiological effects from nuclear explosions in event of attack.

6. Severe Fallout - Moderate Damage

By definition, the shelters in areas in this hazard situation would not be effective in reducing the potential exposure doses sufficiently to prevent radiation casualties or fatalities (if the occupants remained in the area sufficiently long). The range in fallout deposition times in the area, if the severe fallout situation is caused by fallout from a single nearby surface burst, would be about 30 to 80 minutes after detonation. In this event, the pre-fallout arrival countermeasure action would be the same as for the case where the damage occurs before the fallout arrives. The early countermeasure actions given for the moderate fallout - moderate damage situation would be applicable until the severe fallout hazard condition occurs; at that point, it would be evident that remaining in shelter would not be an acceptable alternative unless the exposure dose during an evacuation (or a move to better shelter) were greater than remaining in the first shelter.

Relocation of the population to fireproof shelters from those in areas where the fire threat is large would be included as an action option under the assumption that avoidance of immediate casualties by fire would be preferred over avoidance of later-occurring radiation casualties (use of

such an option, in effect, would assume that the probability for a heavy fallout condition developing during movement was relative low). After identification of the condition of heavy fallout, all short-term out-of-shelter operations would have to be curtailed entirely to minimize fatalities among the survivors; the earlier-time actions are applicable only because conditions corresponding to the no fallout, moderate damage, condition would be identifiable at the time.

If the original condition is that of heavy fallout (and this would only be known after fallout cessation), countermeasure operations applicable to that situation could be underway when a nearby surface or air burst takes place. If evacuation operations were in progress, evacuees could be subjected to the direct effects of the explosion to the degree of severity indicated for the moderate damage area. The survivors of such exposure would have essentially no alternative but to continue their evacuation. In general, all short-term outside operations in the area would lead to deliberate radiation overexposure of the operators.

## 7. No Fallout - Severe Damage

Areas having this hazard situation include those in which the combined physical damage from blast and fire effects on a built-up target area would produce much more debris than that needed to stop vehicular-supported operations without prior debris clearance operations. In this situation, operations would not be constrained by fallout radiation (i.e., no radiological requirements for shelter occupancy would exist). Areas with this situation are not likely to be very large, if they occur at all, following a surface nuclear detonation in the megaton yield range; however, this hazard situation definitely would be a characteristic one resulting from an airburst over an urban target area.

As indicated in previous sections, the distance from ground zero to the outer boundary of the area of severe damage would depend on the

debris-producing potential of the contained structures as well as the blast overpressure and the incident thermal radiation, and the weapon yield and height of burst, and on the amount and kind of debris required to effectively impede movement. Technical data on the analytical methods for relating many of these parameters were summarized in a previous section; future research analysis of inputs to recovery planning would be helpful if directed toward the development of practical information that could be used to better identify specific recovery problems for this situation as well as to further specify operational and organizational requirements of debris removal and recovery of the operation of damaged vital facilities.

As indicated above, operations in an area in this situation would be limited to those that could be carried out on foot, are airborne, or are by water. The degree of physical damage and amount of debris in areas having heavier structures would increase with decreasing distance from ground zero. The overall survival rate of sheltered persons would decrease with decreasing distance from ground zero. Because of restrictions on movement and likely loss of water supplies, all fires in the area would be uncontrolled fires; but as mentioned previously, these fires would probably not be as intense as similar fires in the outer fringes of the moderately damaged area.

The possibility of exposures to prompt or initial nuclear radiation is rather remote for present shelters because of the overriding consequences from the blast and thermal effects of nuclear explosions in the megaton yield range. For example, if a 5-MT air burst were detonated at the height for obtaining maximum range of the 6-psi overpressure, the potential gamma radiation exposure dose directly under the explosion, (i.e., at ground zero) would only be about 0.0005 roentgens.

Major immediate and transattack countermeasure operations in the severely damaged areas would generally be restricted to very localized operations by survivors in the heavier buildings or in underground shelters because of the debris and fire threat; possible actions include:

(1) Fight fires by ignition suppression in and around shelters in heavier buildings or around underground shelters.

(2) Relocate to nearby fireproof shelters or to fire safe areas until the fire threat diminishes.

(3) Rescue trapped and injured in damaged structures near the shelter locations.

(4) Provide first aid and emergency medical treatment insofar as shelter stocks and capabilities of survivors in heavier shelters permit.

(5) Evacuate on foot, by helicopters, or by boat to nearest reception centers in a Free area.

(6) Evacuate on foot to nearby open areas (i.e., to moderately damaged or Free areas) or to the periphery of the heavily damaged area for transport to reception centers.

With a few minor exceptions, all of the above-listed alternative countermeasure options are of the self-help or mutual assistance category for groups of survivors until they make their way to the periphery of the area. In regions with structures of high fire susceptibility, the relocation or evacuation movements should probably be initiated as soon as it became evident that ignition suppression efforts were not successful. Along this line, further research is needed to better define high fire susceptibility limits for structures of modern cities subjected to severe damage in terms of fire intensity and the possibility of movement in the streets (the time scale requirement could well be very different from that deduced directly from World War II experiences).

Major postattack countermeasures in the area, conducted mainly from peripheral staging areas after the early-time evacuation and after the fires have burned out, include:

(7) Debris clearance of access and through-routes.

(8) Rescue of trapped survivors.

(9) Removal and burial of dead.

(10) Damage repair of recoverable equipment and facilities.

(11) Salvage of equipment and supplies.

(12) Reconstruct vital utility service facilities and other repairable facilities in the area whose outputs are needed in other zones (no housing except scattered units in heavy buildings would remain in an urban area on which severe damage was inflected).

Additional summaries of available information and data analyses would be helpful for identifying the types of resources that could be expected to survive in residential, industrial, and commercial districts when subjected to the effects defined for the heavily damaged area. At some point, depending on height of a burst point and weapon yield, destruction of resources would be so great as to make any salvage operation a waste of effort for a considerable period of time after attack.

8. Moderate Fallout - Severe Damage

The severe damage situation countermeasure options would be as given above, but in this situation they would be constrained because of the presence of the fallout hazard. If not so constrained, overexposures leading to radiation sickness and some fatalaties would result.

Major transattack countermeasure operations for the situation in which the moderate fallout hazard develops from an upwind surface detonation following receipt of heavy damage from a nearby airburst would include (assume that prior initiation of countermeasures applicable to situation No. 7 would have been accomplished):

(1) In firesafe regions where ignition suppression actions have been successful, remain in shelter until feasible conditions exist to evacuate to a no fallout, moderate damage, or Free area location.

(2) In high fire susceptible regions where ignition suppression actions have not been successful, evacuate to firesafe sections or to areas with lower fallout and damage levels.

(3) Where the first alternative is possible, carry out, on a short-term basis, outside rescue and other necessary operations in the vicinity of the shelter.

Where fallout from an upwind surface detonation occurred prior to a nearby airburst, the moderate fallout condition would have been identified if fallout cessation took place prior to the nearby explosion. For this combination of events. several of the no fallout - severe damage situations operations following the nearby detonation would have to be considered in spite of the radiological hazard; these and other possibilities are:

(4) Fight fires by ignition suppression in and around shelters in heavier buildings or around underground shelters.

(5) Relocate to nearby fireproof shelters or to firesafe areas taking advantage of any available shelters (some of these movements could well result effectively in a change to heavy fallout hazard situation) until the fire threat diminishes.

(6) Evacuate to areas with lower fallout and damage levels.

(7) Stay in shelter (as in 1 above) and conduct feasible outside operations (as in 3 above).

9. Severe Fallout - Severe Damage

For the case where the fallout is produced by the same detonation causing the damage, the resulting size of area having a severe fallout - severe damage situation would be very small; the area would necessarily be located near ground zero. In such a region, all structures except deep underground shelters would be destroyed and survivors would be few. Immediate evacuation on foot over the debris to any other affected area is about the only countermeasure reasonable to survirors. (People in the deep underground shelters could evacuate or be evacuated at a later time.) The implied correlation of the high degree of damage with a high

level of fallout may not always apply since the displacement of the high fallout levels near ground zero would depend on the local windspeeds at the time of detonation.

In the case where the fallout from an upwind surface detonation arrives first, the prior identification of a severe fallout - no damage situation is possible and countermeasures appropriate to that situation could be already in process when the nearby detonation occurs. The degree of damage, for this combination, could change gradually over the range depicted for the whole region of severe damage. Even though radiation overexposures are inevitable in the described situation, the major countermeasure alternatives would be about the same as given for the areas receiving moderate fallout and heavy damage.

## REFERENCES


1. Glasstone, S., ed., The Effects of Nuclear Weapons, U.S. Government Printing Office, 1962

2. Miller, C. F., Fallout and Radiological Countermeasures, Stanford Research Institute, Project 4021, January 1963

3. Miller, C. F., Civil Defense Operational Concepts, URS Research Company Project, URS 757-1, May 1969

4. Edmunds, J. E., Debris Prediction Model, URS Research Company Project 686-10, June 1969

5. Wickham, G. E., and T. N. Williamson, Operational Planning Debris Removal, Jacobs Associates Technical Report No. 110, July 1971

6. Bond, V., Fire and the Air War, National Fire Protection Association, Boston, Mass., 1951

7. Goodale, Thomas, Effects of Air Blast on Urban Fires, URS Research Company Project URS 7009-4, December 1970

8. McAuliffe, J., and K. Moll, Secondary Ignitions in Nuclear Attack, Stanford Research Institute Project 5106, July 1965

9. Vodvarka, F. J., and T. E. Waterman, Fire Behavior, Ignition to Flashover, IIT Research Institute Project N6059, June 1965

10. Takata, A. N., Fire Spread in High-Density High-Rise Buildings, IIT Research Institute Project J6095, Jebruary 1971

11. Brunswig, Hans, Practical Experiences of Fire Protection Services, Institute for Defense Analyses, June 1966

12. Miller, R. K., M. E. Jenkins, J. A. Keller, Analysis of Four Models of the Nuclear-Caused Ignitions and Early Fires in Urban Areas, Dike-Wood Corporation Project DC-FR-1210, August 1970

13. Butler, C. P., Measurements of the Dynamics of Structural Fires, Stanford Research Institute Project PYU-8150, August 1970

14. Wiersma, S. J., and S. B. Martin, Measurements of the Dynamics of Structural Fires, Stanford Research Institute Project PYU-8150, August 1971

15. Miller, Carl F., Fire Fighting Operations in Hamburg, Germany, During World War II, URS Research Company Project URS7004, June 1971

16. Shirabe, R., Medical Survey of Atomic Bomb Casualties, Research in the Effects and Influences of the Nuclear Bomb Test Explosions, Vol II, Japan Society for the Promotion of Sciences, Veno, Tokyo, Japan, 1956

17. Goen, R. L., The Magnitude of Initial Postattack Recovery Activities, Stanford Research Institute Project EGO-7979, December 1971

18. Miller, C. F., and J. W. Kerr, Field Notes on World War II German Fire Experience, Stanford Research Institute Project MU-5070, October 1965